Chapter 4
Important Parameters for Image Color Analysis: An Overview

Juliana F. S. Gomes, Fabiana R. Leta, Pedro B. Costa and Felipe de O. Baldner

Abstract In recent years it is noteworthy how the use of Computational Vision techniques in processing and quality control of products has advanced. The available resources in both electronic and computing were important factors in the automation development, allowing constant monitoring during the process. Such techniques have systematically evolved in the international commerce. However, there is a lack of standardization on quality control of products using image analysis. Measurements using digital image should consider important aspects, such as the effects of lighting, characteristics of the environment, the types of illuminants, the observers, to name a few, all that beyond the traceability of the system and the definition of standards. With this in mind, the aim of this chapter is to discuss the relevance of the main variables that influence the color measurement of images using computer vision techniques, in order to promote some thought about the needs of standardization.

Keywords Color analysis by image · Illumination · Color perception · Color rendering index · Color temperature

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List of Abbreviations

CVS	Computer vision systems
LED	Light-emitting diode
CT	Color temperature
CCT	Correlated color temperature
CCD	Charge coupled device
CMOS	Complementary metal oxide semiconductor
CIE	*Commission Internationale de l'Eclairage* International Commission on Illumination
CRI	Color rendering index
SPD	Spectral power distribution
RGB	Red, green, blue color system
HSL	Hue, saturation, lightness color system
HSI	Hue, saturation, intensity color system
HSB	Hue, saturation, brightness color system
HSV	Hue, saturation, value color system

4.1 Introduction

Visual inspection, despite being a technique that dates from centuries ago, is still a widely used nondestructive test that is able to assess the quality conditions of materials due to its ease of performing, inexpensiveness and generally requirement of no special equipment. This technique is considered a primary method in quality control programs needing an observer with good vision and technical experience in the recognition of defects, as well as good lighting conditions.

With the development of computer software, digital cameras, computers with greater resources and interfaces, together with a decrease in prices, and better access to new technologies, the field of Computer Vision has emerged as a tool for developing innovative methods of nondestructive testing with applications in the most diverse areas. The use of automated inspections in industries is becoming an increasingly attractive solution, especially for compliance analysis, defects search, and final analysis of product quality. Unlike the problems presented for visual inspections performed by humans, these types of systems can provide repeatable measurements without any kind of physical contact, eliminating aspects such as subjectivity, fatigue, and cost associated with human inspection as well as increasing how fast each product is inspected. These comprise many reasons for the use of such new methods of measurement, which may involve not only dimensional aspects, but also appearance characteristics, such as in food, textiles, cosmetics, paints, and automotive, encompassing all industrial sectors.

The use of automated inspections in industries has become an attractive solution in the final analysis of product quality, which considers the characteristics of color, texture, and shape, which are the usual criteria used by consumers when purchasing a product [1, 2]. The main challenge for these inspection systems is to combine the image quality results with lower costs and losses in the process, especially considering the accuracy and reliability of the process. Because of this, each system should be developed and configured properly in order to consider its reproducibility and traceability, making it a challenge for the industry, requiring a greater interface between the professionals of the fields of Engineering, Metrology and Computation.

This work has the purpose of discussing the main parameters that influence color measurement in images using computer vision techniques.

4.2 Computational Vision Systems

Computer Vision is the science responsible for the study and application of methods that enable computers to understand the contents of an image and interpret important features extracted from this image for a particular purpose [3].

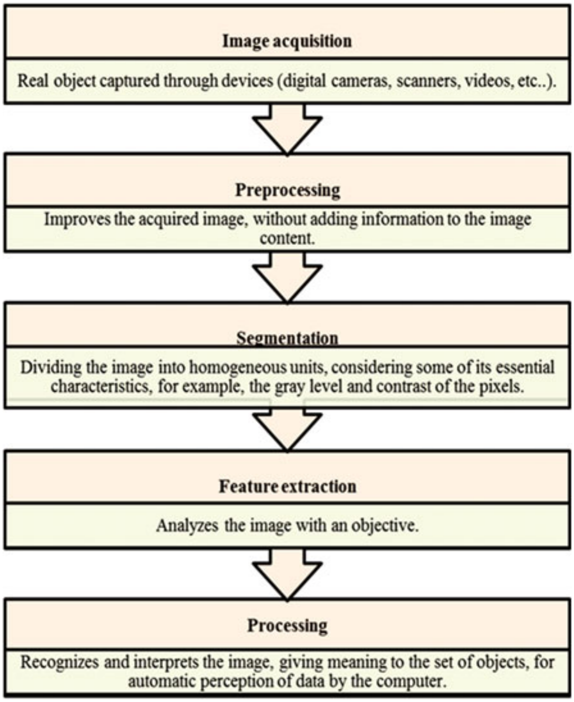
The development of Computer Vision Systems (CVS) requires an input data that is usually obtained from sensors, cameras, or videos, which is an image. The image is then processed and transformed into some sort of expected information. Even though a CVS should be organized according to its application, there are typical steps for all CVS, which can be summarized as: image acquisition, preprocessing, segmentation, feature extraction, and processing (analysis); all of these are shown in the block diagram of Fig. 4.1.

In the image acquisition step, the image of a real object or a scene is transformed into a digital image using an acquisition device (digital cameras, scanners, videos, etc.). To represent and manipulate these digital images it is necessary to create mathematical models suitable for this purpose. These are constructed from an image of the real object, which undergoes a transformation in order to be verified. This scanning process generates a continuous mapping of the actual image, which is discretized at various points, called pixels. A matrix is then formed in a way that each position (x, y) that has information on the gray level or color associated with $f(x, y)$. The color is represented by color systems and the most widely used systems are the RGB and HSL.

The preprocessing is the step prior to feature extraction, which aims to improve the acquired image. It can enhance visibility and the separability between the background and the objects, without adding information to the image. Among the techniques of preprocessing, it is possible to highlight the transformation to grayscale, as well as thresholding and filtering.

After the preprocessing there is the segmentation step whose purpose is to divide an image into homogeneous units, considering some of its essential characteristics, for example, the gray level of the pixels and texture contrast. These units are called regions and may correspond to objects in a scene, and are formed by a group of pixels with similar properties. Through this process of dividing an image into regions, which will simplify and/or change its representation, it is

Fig. 4.1 Typical steps of a computer vision system



possible to interpret it more easily. After these steps, the image should be ready to have its characteristics of interest obtained.

Lastly, the processing step recognizes patterns and interprets the image, giving meaning to the set of objects in the image, in order to improve on human visualization and the perception of the data automatically by computer.

Currently, computer vision has been used in various industry sectors, contributing significantly in many stages of the production cycle of a product, such as robot control, task automation, production planning, and quality control. In terms of hardware, a CVS is basically composed of a light source, a device for image capture and a computer system, as shown in Fig. 4.2. A CVS is usually used in production lines where human activity is repetitive and tedious. In this situation, products are manufactured very quickly requiring fast and accurate measurements, necessary for making decisions during the process.

4.3 The Color Perception

Currently, color theory can be divided into three main sorts: physical color (physical optics), physiological color (physiological optics), and chemical color (physicochemical optics). Thus, the phenomenon of color depends on the nature of

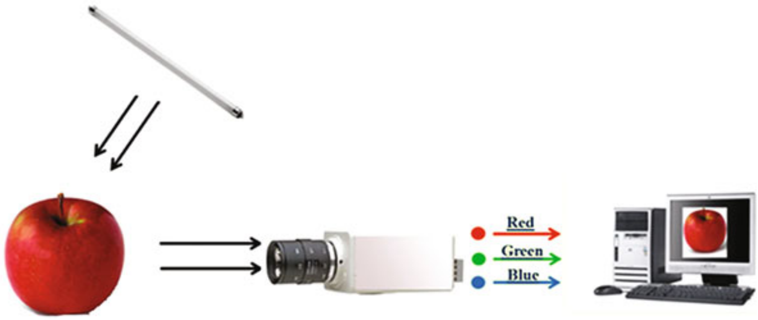


Fig. 4.2 A basic computer vision system schema

light (light source), the interaction of light with materials and the physiology of human vision.

It is known that a light source comprises any process able to emit, re-emit, or conduct energy in sufficient quantities to produce light, in other words, produces electromagnetic radiation whose wavelengths are inside the visible region. There are basically two types of light sources: natural light, such as the sun, and artificial light, which can be based on different types of technologies, such as incandescent lamps, fluorescent lamps, LEDs, among others. The distribution of the electromagnetic radiation emitted by these lamps depends on the emission material and the conditions of its use.

The electromagnetic radiation originating from the light sources interacts with various types of materials. Each material has its own characteristics due to their molecular formation, thus presenting different properties when it interacts with light. The result is the material color, which depends on its pigment constituents.

Therefore, a beam of radiation that is emitted can undergo reflection, transmission, or absorption when it focuses on a particular material. It is noteworthy that every material absorbs radiation in some part of the electromagnetic spectrum and the quantity of energy absorbed relies on the selectivity of the absorbing material (pigment) and the wavelength of the radiation.

Thus, one can consider two different types of color: the color originating from a light source and the color pigment originating from a particular material, making the task of specifying color impossible without including the knowledge of the radiation source, since it provides the light that is reflected by the material that, in turn, causes the color perception in the human eye, as shown by Fig. 4.3.

The electromagnetic radiation emitted from light sources or from objects due to reflection or transmission is perceived by the human vision system with the photosensitive cells present in the retina, as seen above in Fig. 4.3. The physiology of the human eye states that the retina is composed of two types of receptor cells that, due to their shapes, are called rods and cones. The cones are found primarily in the center of the retina and are responsible for vision with higher brightness, known as photopic vision. They are also responsible for color vision, being

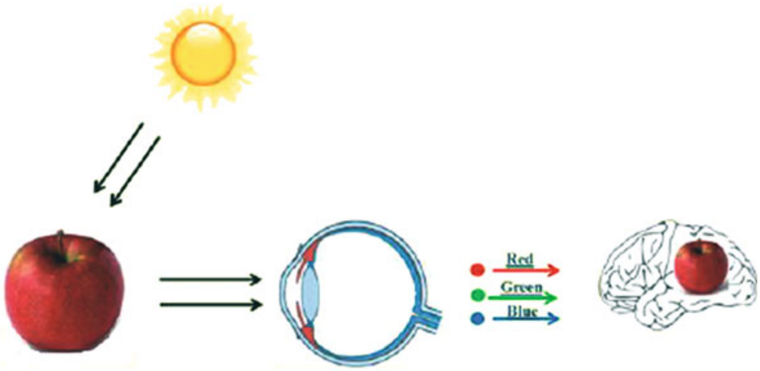


Fig. 4.3 A basic human vision system schema

sensitive to long, medium, and short wavelengths (red, green, and blue), commonly known by their initials in English R, G, and B. The rods are located at the outer edges of the retina and are responsible for vision in low light, being sensitive only to shades of gray.

It can be concluded that the phenomenon of color depends on the nature of light (light source), the interaction of light with materials, and the physiology of human vision. In summary, the phenomenon of color perception is based on our body's response to stimuli received from an electromagnetic radiation originated from a light source, reflected or not for a given material and focusing on our eyes.

To standardize the identification of colors it is necessary to define some characteristics of the light sources in order to standardize operating conditions. One is the color temperature (CT), which expresses the appearance of the color of the light emitted by the light source. Its unit of measurement is the Kelvin (K). The higher the CT, the brighter the hue of a light's color. The correlated color temperature (CCT) is defined as the temperature of the Planck radiator whose perceived radiation more closely resembles that of a given stimulus with the same brightness under specific observation conditions [4].

4.4 Color Analysis Using Image

The perception of an object (or of the acquired image of an object) is a function of the spectral property of this object, the lighting, and its acquisition (human or not). It is known that the phenomenon of color depends on the nature of light (light source), the interaction of light with materials, and the physiology of human vision (or image acquisition device). The phenomenon of color perception is based on the body's response to stimuli received from an electromagnetic radiation originated from a light source, reflected or not on a given material, focusing in the viewer's eyes. Likewise, the acquired image of an object is a function of the spectral

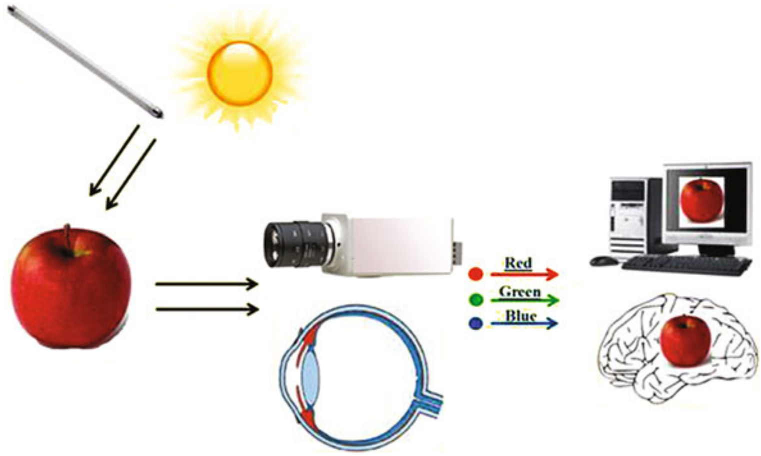


Fig. 4.4 Computer vision system × human vision system

property of the object, lighting, and camera in response to the stimulus received, as compared by Fig. 4.4.

Just like the human eye, a digital camera has sensors that convert radiation (stimulus) into electrical charges, which are then digitalized. The image sensors used in most digital cameras are charge coupled device (CCD) or complementary metal oxide semiconductor (CMOS). Each sensor is composed of two filters, one black and white with sensitivity to different intensities of radiation and another sensitive to red, green, and blue, called the Bayer filter, deployed in order to make the acquisition of radiation by the camera as similar as possible to the human eye.

Comparing the spectral distributions of filters used in some models of cameras, one can observe a difference between models and manufacturers. Comparing the spectral distribution of the cameras with the distribution of color equalization functions of *Commission Internationale de l'Eclairage*—the International Commission on Illumination (CIE) there is a big difference between them, technically demonstrating the need for calibration and characterization of these when used in quantitative automatic inspection systems.

The process of image digitalization is generated from the mapping of an analog image, in which the latter is divided into several points, forming a two-dimensional array $f(x, y)$. Each point of this matrix is called the pixel of the image, and, due to the color filter used, these two elements are connected with the spatial resolution of the image's color, which is typically represented by color systems to enable their representation. Similarly to the human eye, the color system that is most similar to the image acquisition system is the RGB due to the formation of the three additive colors red, green, and blue.

Various features can be extracted from the RGB values obtained during the processing step, including some appearance characteristics such as the color. Other color systems are also used in the analysis of color of an image from the conversion of RGB values in other systems, such as HSL, HSI, HSB, and HSV that are widely employed since they consider concepts of hue, saturation, and brightness.

For calibration of digital cameras it is necessary to convert the different color systems used into a color system that is known to be subsequently compared with standards previously calibrated in order to give the system the necessary traceability. The color system used in such calibrations is the CIEXYZ color system, developed by the CIE to be used in colorimetry and, from this, other color systems can be used according to the need of the application area. In the industrial area the most used color system is the CIELAB because it is the closest to human perception.

4.4.1 Parameters Influence

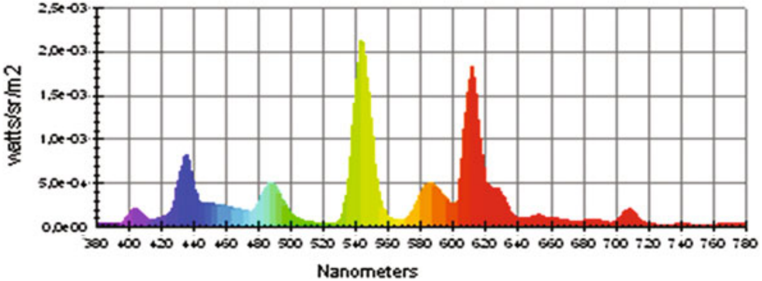
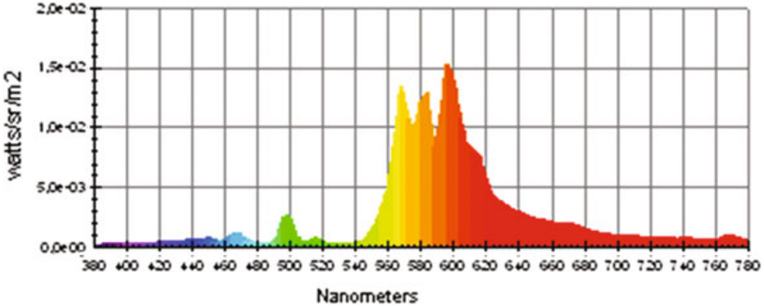
Because an object's color is one of the main indicators of perception of the products quality, the factors that influence color analysis should be considered in the system of visual assessment.

The image acquisition step is a physical process that depends on a large number of parameters for obtaining a quality final image. Some parameters influence the image quality to be obtained, such as the device used to acquire the image, the lighting system used, and the background color. There are many types of devices used in image acquisition, such as digital cameras, scanners, video cameras, and thermal. The most commonly used devices are digital cameras, which cover about 58 % of the total of devices [1]. Another important parameter in the image acquisition device is a detection system, which can be CCD or CMOS, since each has differences in the speed of image acquisition and sensitivity to light, both of which have advantages and disadvantages that must be studied case by case.

The type of lighting is also of influence in the resulting picture. It is important to note that some features of the light source used, such as CCT and color rendering index (CRI), are decisive in the final perception of the image and should be set according to the research objective [5]. There are many light sources available, which have quite different properties between each other. Thus, to standardize the identification of colors it is necessary to define some characteristics for the light sources, such as the CRI and CCT [4]. With the knowledge of the Spectral Power Distribution (SPD) it is possible to calculate the CCT that expresses the color appearance of the light emitted by the source. The CCT increases from red to blue; the higher its value is, the brighter will be the color hue of the light, and the lower, the more yellowish, thus influencing in the perception of the color of the material. Lamps with CCT below 3,100 K are considered "hot", and those with values above 4,100 K are considered "cold" while those in the range of 3,100–4,100 K, are considered neutral color or moderate (Table 4.1).

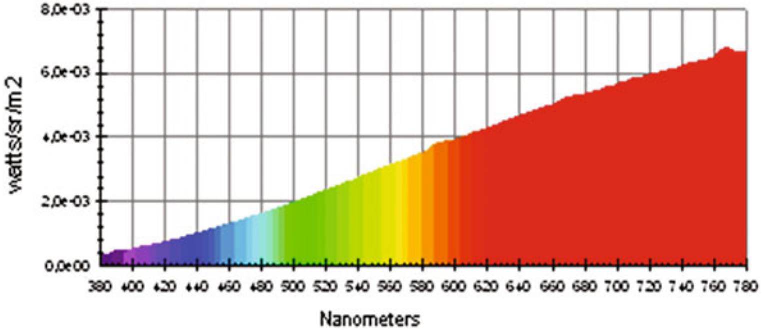
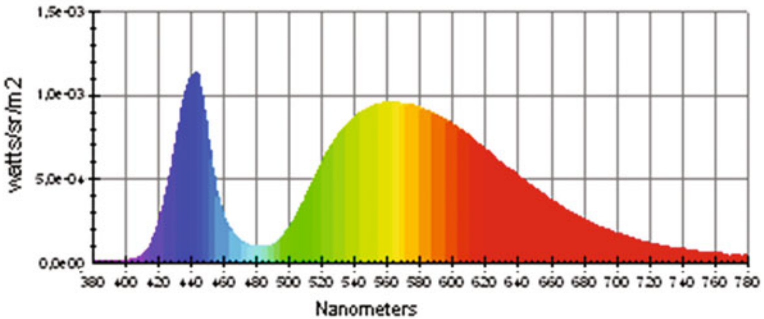
The CRI is also an important parameter, quantifying the fidelity with which the colors are reproduced when struck by a particular source [6]. The CRI is calculated

Table 4.1 Examples of SPD of some light sources [9, 10]

Source	Spectrum	CCT (K)	CRI
Fluorescent		3,834 ($U_{CCT} = 47$ K)	60.2 ($U_{CRI} = 2.7$)
High pressure sodium vapor		2,059 ($U_{CCT} = 13$ K)	22.4 ($U_{CRI} = 1.9$)

(continued)

Table 4.1 (continued)

Source	Spectrum	CCT (K)	CRI
Incandescent		2,856 (U_{CCT} = 21 K)	99.8 (U_{CRI} = 2.3)
LED		4,284 (U_{CCT} = 69 K)	67.2 (U_{CRI} = 1.8)

from the SPD of the source, and is an average calculated from the difference in color of a prespecified set of samples under both a reference illuminant and a test illuminant [7]. The best performance of a light source, when compared to a given reference, generates a CRI of 100. A CRI greater than 80 is generally acceptable depending on the requirement of the application that a lamp must meet [8] (Table 4.1).

The types of illumination most commonly used are fluorescent lamps (65 %), incandescent bulbs (10 %), natural lighting (19 %), and LED (2 %) [1]. Undoubtedly natural lighting would be the best option; however, its characteristics widely changes depending on the sun angle, time of day, weather conditions, etc. Incandescent lamps have a high CRI value, but have high energy consumption and its usage has been avoided. The technology of fluorescent lamps has replaced incandescent bulbs, but their characteristics are varied depending on the composition (amount or type of phosphorus) and it also contains mercury. Even so, its consumption has greatly increased, especially with the use of compact fluorescent lamps, due to their low power consumption and reasonable lifetime.

So, the lighting used to characterize a material must be selected regarding the properties of the source (lamp) and its application in particular cases requires experimental testing [9].

Mohan et al. [11] determined in a comparative study that the reflectance of grains in the near infrared region allowed for a better classification accuracy than the reflectance in the visible region, thus enabling the choice of the best source to be used in the classification of grains. Manickavasagan et al. [12] studied the influence of three types of lighting in the classification of grains: incandescent with 2,870 K, fluorescent ring with 3,000 K and fluorescent tubular with 4,100 K. They both concluded that fluorescent lamps of the T8-type, normally used in classrooms, have better accuracy for identifying defects in grains compared to halogen bulbs, because these have a greater emission of radiation in the infrared region, thus confirming the study by Mohan et al. [11].

The background color has a direct influence on the analysis of color, being another important parameter for image acquisition. Research demonstrates that the background where the material is analyzed can influence the perception of the color of the material [13–15]. According to Brown and MacLeod [13], the perceived color of a scene relies on the ratio between the light signals from that point and light signals from surrounding areas of this scene.

Because the appearance of objects influences directly the consumer's decision about the quality of the product, Dobrzański Rybczynski [16] studied the influence of the packaging of fruits and vegetables in color perception. In this study, oranges, carrots, beetroots, and parsleys were packed with nets of different colors in order to analyze their influence on color and consumer preference. It was concluded that the red colored net influences the color of the orange, appearing to be a more mature fruit, influencing the final consumer.

Black or white backgrounds are the most used [17] because, for the purpose of the analysis, they facilitate the segmentation stage. Blasco et al. [18] presented a study varying the background color in the selection of pomegranate seeds, concluding that the blue background contributed to a better segmentation.

The diversity of industrial products (which have a variety of sizes, shapes, textures, and color) emphasizes the importance of defining standardized parameters during the classification and packing [1], since inadequate illumination may hinder the identification of defects and the color of the products analyzed [9] and the lack of standardization of the background color used for the classification of products (usually conveyor belts or benches) can impair selection process.

4.5 Case Study

Gomes et al. [19] developed a research in order to define a new method for nondestructive testing using colorimetric techniques and computer vision for characterizing color using digital images applied to integrated fruit production, focusing on standardization of measurements, considering the factors of influence. In the initial study, the banana was chosen as a case study in the development of this research, and as a result, a new methodology was developed to characterize the stages of maturation of banana using colorimetric analysis, proposing a standard for the industry [10].

Figure 4.5 shows an example of visual assessment in monitoring of the banana ripening for selection and fruit trade [10] using a halogen lamp as source (CCT = 2,856 K, CRI = 99.8) and black background.

Figure 4.6 shows the difference of perception in an image when using different types of illumination. Figure 4.7 shows the difference in perception of the image when different background colors are used [10].

Large color differences were found when comparing the same ripening subclass using different sources. Such differences justify the need for greater concern about the lighting system employed in the classification area. When comparing different background colors, red and blue backgrounds offered most influence on the evaluation of ripening subclasses.

Therefore, one should evaluate the characteristics of interest to define the parameters to be used in image acquisition in order to get a better image and better accuracy in measuring color from the image. For improving the results it is suggested the following steps for defining an image acquisition system for color analysis: a study of the sample; a study of the best background color; a study of the best light source; and finally the calibration of the measurement system under these conditions (Fig. 4.8).

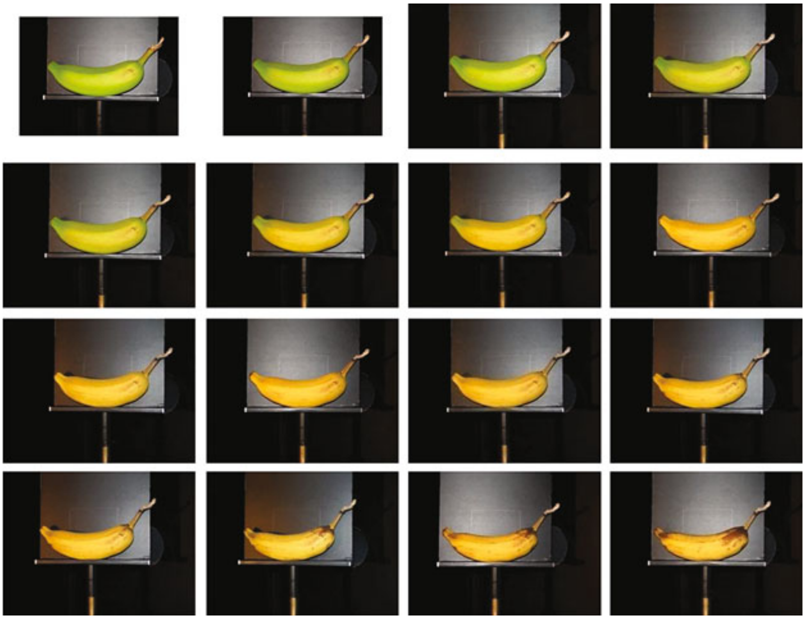
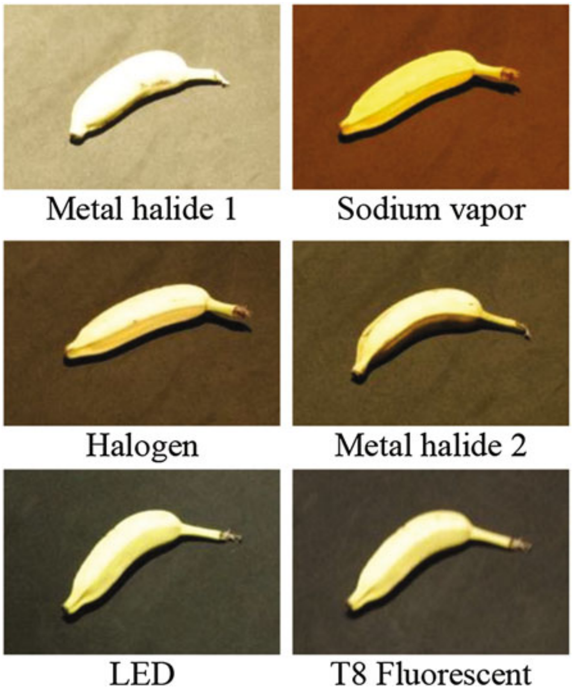


Fig. 4.5 Daily evolution of the ripening of banana 'Prata'

Fig. 4.6 Fruit analyzed under different *lighting* [10]



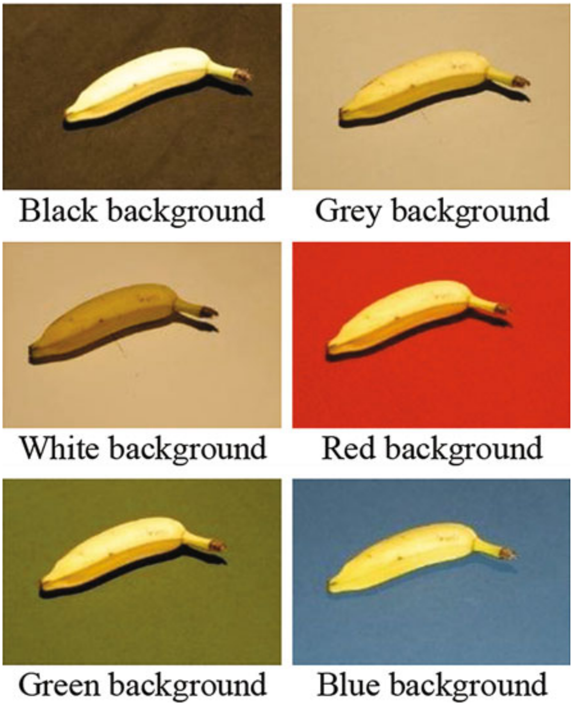


Fig. 4.7 Fruit analyzed under different *background colors*

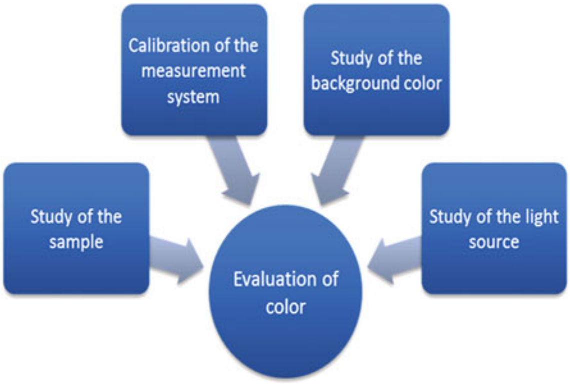


Fig. 4.8 Summary of the proposed methodology

4.6 Conclusions

Several methodologies have been proposed in order to characterize different types of materials for computer vision in so that the inspection process is optimized and losses are minimized. Many works have been developed to increasingly improve the systems of production and the quality of products. In general, most CVS have well-defined five steps. But there is no agreement in what are the right tools and strategies for image acquisition and processing. Each of the technological options presented have their particular response. However, there is an emergent need to develop such methodologies in order to meet a great ongoing demand and cover all the requirements and restrictions of existing procedures due to the specificity of each product, also aiming to standardize these new technologies.

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