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Apple quality study using fringe projection and colorimetry techniques

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ABSTRACT

Fringe projection technique was used to evaluate the changes in topography of apple samples which were evaluated over time. Since for the food industry the color and texture of fruit are also important, thus, measurements of appleís variations in color and shape were made to evaluate the degradation of the fruit over time. Measurements of an apple topography, color, moisture and firmness were done and compared every three days during a period of two months in which the samples were stored under refrigerated conditions. Experimental results of color changes (RGB and L*a*b*) and size changes and their relation to the apple quality are presented.

1. Introduction

Optical techniques are commonly used in the food industry, and provide from a registered image information on food surface quality like color, texture, shape, and size among others [1]. The methodology includes the image acquisition, processing and analysis, which is a non-destructive study to visualize the quality of characteristics of food products [2]. The visual properties correlate well with many physical, chemical, and sensorial indicators of food quality [3], and within these, the color is one of the most important features because it contains the basic information corresponding to human visualization of the product, since it plays a major role in the assessment of external quality in the food industry [4]. In the same way, size is another important aspect of external appearance in food and it is related to the geometric reproducibility of the product in the food conservation processes, since the food volume changes during its processing [5] mainly due to moisture and firmness loss [6]. These physical changes are more evident in fruit during storage, and some fruit is more influenced by refrigerated storage than other, such is the case of apples. During refrigerated storage, the darkening of the apple's skin and moisture loss caused by the ripening process decreases perceptions of color and volume, which influences the estimation of the apple quality [7]. The apple production industry needs to apply methods for fast and accurate measurement of color and volumes, in addition that both parameters can be related in a single measurement.

Furthermore, in optical techniques, image texture is the perceived variations in scattered light from structural changes in the surface of an object [8,9]. The texture of a sample can be related to the variation of intensity of pixels, which is related with the combination of color on the surface of the sample. Finally, the number of pixels defines the size of the sample and

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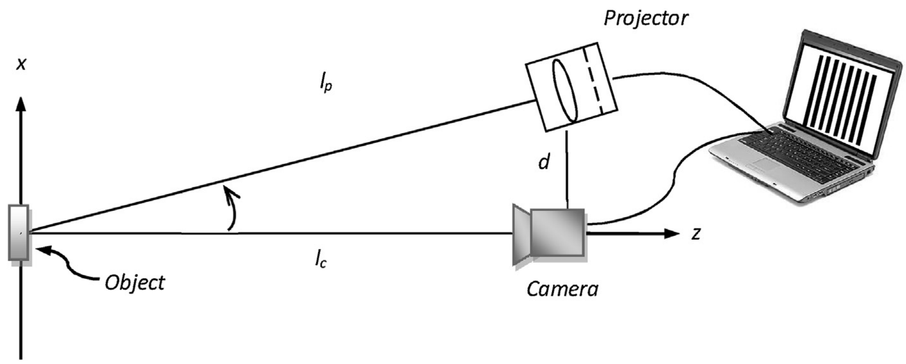

Fig. 1. Experimental setup for a fringe projection system.

its shape. In this regard, optical techniques can be applied particularly in the determination of color, size, and shape of apple during refrigerated storage.

The structured light technique is useful to quantify both macro surfaces [10] and micro surfaces [11,12]. One of the most commonly used among structured light techniques is fringe projection, because it provides high vertical and lateral resolution over full-field of object observation [13,14]. There are several methods used for analysis of registered by camera fringes. By using the Fourier transform analysis method, the phase encoded in fringes and representing object's shape is calculated from only a single image. Using a phase shifting method, the phase is obtained from a set of images. Having phase information and knowing the sensitivity vector of the optical system, the true height $z(x, y)$ at each objectís point can be determined. In fruit tissue, the fringe projection technique has been used to retrieve topographic maps of cuticles surface of leaves from an apple tree (Malus domestica) of the variety Golden Delicious [12]. This technique is related to an optical triangulation method which uses a projection of single point or line of light in light sectioning onto an object and viewed at a different direction to determine the surface contour [15].

The methods for assessing the quality of food products, either by sensory analysis or by instrumental techniques, are frequently destructive and time-consuming, and therefore, they do not fit the conditions for a routine online analysis in an industrial environment. The optical techniques can produce fast and objective results and are non-destructive and non-invasive measurements techniques, with low cost-effective technology that can cater the needs of the demanding food industry providing high sensitivity to measurement.

In this paper, we used the fringe projection technique with a set of four step phase shifted fringe images and colorimetry study, for the measurement of topography and color of apple samples during refrigerated storage and related with the measurement of water content and firmness of apple obtained with food industry instruments. Because color is a subjective sensation and it depends on the observer [16], all the optical devices involved in the experiment were properly calibrated.

2. Theory

2.1. Fringe projection

Fig. 1 shows an optical geometry of the fringe projection system where one can obtain the relationship of the measured phase to the height of the object under study with respect to a reference plane. System projects an image of amplitude grating with lines parallel to the y axis. The z axis coincides with the direction of observation and the xy plane ($z = 0$) is a reference plane; i. e. the height is equal to *0* on this plane. The normal of the projected grating makes an angle θ with respect to the optical axis of imaging system. The surface is illuminated with a cosine grating and observed by a charge-coupled device (CCD) camera placed on the normal to the xy plane. In the case of collimated illumination, the mathematical relationship between the height of the object, the phase and the parameters of the experimental optical system is given by Eq. (1) [15]:

$$z = \frac{\varphi}{2\pi} \cdot \frac{p}{\tan\,\theta} \quad (1)$$

where the phase φ can be obtained with the phase shifting method [17], and p is the period of the grating projected onto the plane $z = 0$.

The intensity function of the projected fringes, is given by the Eq. (2):

$$I(x,y) = a(x,y) + b(x,y)\cos[\phi(x,y)\Delta\phi] \quad (2)$$

where $a(x, y)$ describes the variations of the intensity background, $b(x, y)$ describes the amplitude of the fringes, $\phi(x, y)$ is the phase information and $\Delta\phi$ is an introduced phase shift. Thus, at least three-steps are needed to obtain the phase information.