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Comparison of TOF and SL techniques for in-line measurement of food item volume using animal and vegetable tissues

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ABSTRACT

A comparison between the techniques Time of flight (TOF) and Structured Light (SL), for in-line process, was carried out to determine the volume of several food types with different compositions, structures and dimensions; 2 meat tissue (lean meat and pork fat) and 3 vegetable tissue (potato, apple and avocado). The volume obtained was compared with that determined by physical measurements, employing two statistical methods (a Bland–Altman study and partial least square analysis). Results showed that Structured Light (SL) was a better technique than Time of flight (TOF) for determining volume. The TOF technique was affected by factors which were more influential when the S/V ratio (surface of the sample exposed to the camera and sample volume) increased. SL was slightly affected by the composition of the sample. Fat content and the level of unsaturated fatty acids could be the reason for the reflection of the laser light on the surface of the samples thereby reducing the accuracy. Even so, the values of R^2 and RMSE of cross-validation, for the worst fit, demonstrated the quality of the SL technique.

1. Introduction

Developing new products and processes are primary objectives for the food industry to increase profits. To achieve these objectives it is necessary to incorporate new methods to enhance the quality, safety and efficiency of traditional processes (Datta & Halder, 2008). Non destructive analysis is an important approach which has wide areas of application. Groups of optical methods have recently been used to study some direct and indirect aspects of food products. 3D image systems are one of these groups. This group of systems applies different techniques, which will probably supplement 2-D machine vision based systems (Poussart & Laurendeau, 1988). In addition, 3D vision systems are solving challenging problems posed by conventional 2D imaging techniques (Mufti & Mahony, 2011), resulting in an increased interest and demand for this type of system.

The 3D digitized geometry of food can be very interesting to model transformations and processes. For example, Fabbri, Cevoli, Romani, and Rosa (2011) used 3D models to describe numerical models of heat and mass transfer during coffee roasting. Trujillo and Pham (2006) used them to model heat and moisture transfer during beef chilling.

Two different methods of obtaining 3D information are “Time of flight” (TOF) and “Structured light” (SL). The TOF technique (Xu, Schwarte, Heinol, Buxbaum, & Ringbeck, 1998) is based on a camera with a light which illuminates the scene with modulated, incoherent near infrared (NIR) wavelengths, and smart pixel sensors gather the reflected light (Keller & Kolb, 2009) whose return time is measured. A 3D model is generated through the contrast between empty scenes and scenes with object time variations. SL Technique is based on a laser projection of a specific pattern, for example a line on top of an object’s surface, the deformation of this pattern gives information about the surface of the object. This information is collected through a camera and processed to generate a 3D model. Both methods have so far been applied to very different areas. There are few TOF applications to measure 3D objects as this technology is mainly used for mobile robot applications, however this technology could be applied successfully to measure the volume of objects (Ollikkala & Mäkynen, 2007) or even the morphology of plants (Klose, Penlington, & Ruckelshausen, 2009). Regarding SL, there are a lot of food applications such as food density prediction using acquired 3D information (Kelkar, Stella, Boushey, & Okos, 2011), 3D shape construction of tomatoes (Hatou, Morimoto, De Jager, & Hashimoto, 1996) or surface area and

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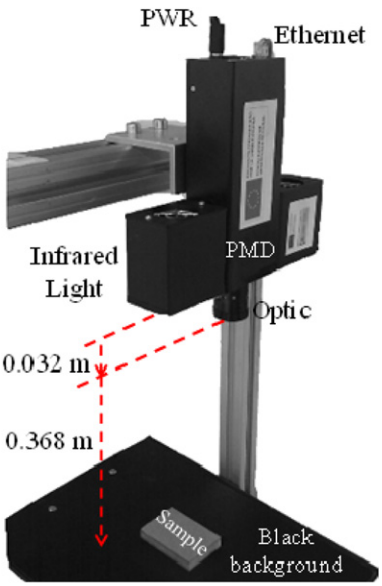

Fig. 1. 3D capture equipment based on time of flight.

volume estimations of different food products (apple, pear, banana and strawberry) (Uyar & Erdoğdu, 2009). But in these studies the volumes were obtained employing a 3D laser scanner with off-line data processing which means the technique is not suitable for working in an industrial application.

The aim of this work was to study the viability of TOF and SL methods, working in-line, to calculate the volume of different foods using 3D models. Food samples with different matrices (animal and vegetable) and compositions were employed to evaluate possible influences on the volume obtained.

2. Methods

2.1. Materials

Several types of food with different compositions, structures and dimensions were tested, 2 from meat tissue (lean meat and pork fat) and 3 from vegetable tissue (potato, apple and avocado). Wooden blocks were used as calibration objects since they are solid, have a regular shape and without brightness. For each type of food, five samples ($n = 25$) were cut as cubic shapes with random sizes (from 3.6 $m^3 * 10^{-6}$ to 70.2 $m^3 * 10^{-6}$). Due to the difficulty of regular cuts on lean meat and fat samples, volume was calculated according to equation (1). In addition, for vegetable samples, volume was also calculated employing equation (2).

$$V = M/\delta \tag{1}$$

$$V = LWH \tag{2}$$

where L, W, and H represent the length, width, and height and M and δ represent the weight and density.

Density was calculated using a pycnometer.

2.2. Description of image acquisition device

2.2.1. 3D using “Time of flight” method (TOF)

The Time of flight method is based on the calculation of the time that it takes an electromagnetic or other wave to travel a certain distance through a medium. Knowing the speed of the wave in this medium, the distance can be calculated. In this case, the acquisition device used was the PMD[Vision] 19k camera (PMD Technologies GmbH, Siegen, Germany) (Fig. 1) which provides image and depth information about the scene. The camera sensor is based on CMOS technology formed by 19200 PMD (Photonic Mixer Devices) pixels with a resolution of 160 by 120. In each PMD pixel, the reflected infrared optical signal is correlated to the phase-shifted reference signal directly after charge generation in the photo diode, the distance is then calculated. For details about the features of the PMD imaging system and the phase shifting technique, see for example (Luan, 2001; Plaue, 2006).

Image acquisition was conducted using three different points of view for each sample. It was performed rotating the samples so that all the edges (X, Y and Z) were in a vertical position. Rotation was done in order to take into account a possible influence between the exposed surface and the height of the sample. For each position 50 images were acquired using an integration time of $5*10^{-3}$ s and a frame rate of 1.5 frames per second (fps). Image acquisition was carried out without ambient light, using only the infrared light from the device to avoid noise from other light sources.

The plane background used was a black plane at a distance of 0.4 m from the infrared light and 0.368 m from the optic. An image background was captured without samples in order to subtract this image from the images of the samples and obtain the samples height with positive values.

For each sample position, a temporal filter from the median of 50 depth images and a spatial filter from the median of the pixels with a 9 × 9 window were carried out. Once the 3D image was

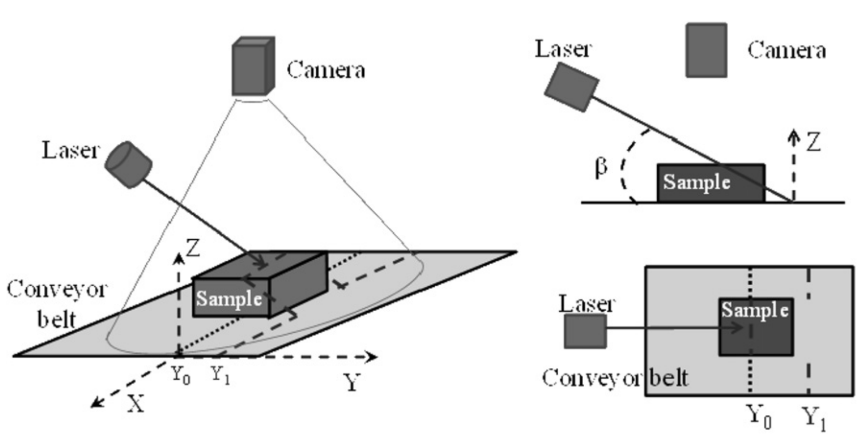

Fig. 2. 3D equipment capture based on structured light.