REVIEW

POTENTIAL OF IMAGE ANALYSIS BASED SYSTEMS IN FOOD QUALITY ASSESSMENTS AND CLASSIFICATIONS

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Abstract

Increasing life standards, developing technology, growing importance of food quality and safety lead food industry to search new analysis methods. In addition, high consumer expectation and increasing population forces manufacturers to find fast and accurate techniques. The present study was aimed to prepare a summary about computer aided image processing systems covering working principles and applications for different analysis of food products. Image processing systems have recently been considered in this extent and results have revealed that computer aided these techniques can provide all these needs in a non-destructive way for samples. These techniques can be adapted to a wide range of food and agriculture products like meat, bakery products, dairy products, vegetables but primarily fruits. Image processing can be utilized for different purposes related to these product groups. Size and shape based classification, defects detection, microbial safety, quality grading and variety determination are mainly investigated topics. Literature survey indicates favourable reported results. Generally small scale investigations have been presented, but some of them could find a place for industrial application with high success. Computer aided image processing has been taken increasing interests of researcher for its potential in the applications for food technologies.

In the present study it was aimed to prepare a summary about computer aided image processing systems covering working principles and applications for different analysis of food products. As a conclusion it could be said that computer aided image processing systems reveal high potential in food industry.

Keywords**:** image processing, fast analysis method, food quality, classification.

Introduction

The developments in the technology, media and communication accompany the increasing awareness of consumers. Therefore, there are more expectations than ever. The situation forces the manufacturers to produce and present higher quality food and agricultural products to market. Moreover, these products have to satisfy sophisticated consumer desires. Computer imaging system is one of the methods serving the assurance for high quality food products.

Product quality is evaluated by a wide range of parameters including external, internal parameters. However, in some cases, sensory and safety scores gain higher importance than above ones. External quality parameters, such as surface colour, texture, presence of bruises and defects, are generally monitored and sorted manually by workers, whereas the internal quality parameters including firmness, pH value, soluble solid contents, titratable acidity are evaluated using common techniques. Sensory (e.g. sweetness, flavour) and food safety (e.g. pathogenic bacteria and faecal contamination, pesticide residues and other hazardous residues) characteristics influence general palatability of the products. However, the old fashion techniques are time consuming, destructive and unable to represent the whole batch (Zhang et al., 2012).

Unlike to traditional ones, computer imaging systems do not cause any damage on/in the product and they are rapid analysis techniques as well as being feasible for in-line process (Kim et al., 2007; Park et al., 2011). Being another advantage, these systems in this extent can be easily implemented for any analysis of an individual object and/or a batch of food and agriculture products, like intact fruits, even as they are on the yards (Stajnko et al., 2004). Against the traditional techniques, intensity of the analysed feature in a bulk is possible to figure out by imaging systems (ElMasry et al., 2012, Feng et al., 2013). Moreover, these systems also provide opportunity to perform rapid, hygienic, automated and objective inspections.

This paper represents an overview on camera imaging systems in the food industry. Basic knowledge is provided about steps and principles, some examples of applications are submitted as well.

Basic Steps of Image Processing and Analysis

Computer vision is a system designed with a few equipment and algorithm which are used to obtain information about objects of interest. The information could be utilized in order to shape classification, quality sorting, identification of internal and external features, etc.

Recognition processes of the specialities of the objects occur with a series of steps. Image acquisition, pre-processing, segmentation, representation and description, recognition and interpretation are basically the steps of the computer vision processes and every step must be implemented carefully, or else the results might be unsatisfactory (Gunasekaran, 1996).

Image acquisition is the stage for turning electronic signals from sensing device into numeric form. Ultrasound, X-ray and near infrared spectroscopy, displacement devices and document scanners, solid state charged coupled device (CCD) cameras are some of the sensors used to create images (Brosnan, Sun, 2004). Thermal imaging cameras (Gowen et al., 2010) and terahertz cameras are also used in image analyses systems (Lee, Lee, 2014). In order to get a high quality image which is a vital factor for sequent steps, illumination and lighting arrangement, high quality optics and electronic circuitry must be prepared properly (Gunasekaran, 1996). Light sources vary according to purpose of using such as incandescent, fluorescent, lasers, X-ray tubes and infrared lamps (Brosnan, Sun, 2004).

Pre-processing stage includes one or more operations of noise reduction, geometrical correction, grey-level correction and correction of defocusing and aims to improve image quality (Shirai, 1987).

Image segmentation is one of the most important stages because accuracy of following step deeply related with this step. It is intended to separate the image into parts which have a strong relation with the object (Brosnan, Sun, 2004). After segmentation, the image generally represents a boundary or a region. First types of images are suitable for size and shape analyses while the latter one is used for determination texture and defects. The image representation should be chosen according to planned application (Gunasekaran, 1996).

Recognition and interpretation are generally performed using statistical classifiers or multilayer neural networks to provide information that is useful for process or machine control needed for quality sorting and grading (Brosnan, Sun, 2004). Fuzzy logic, decision tree and genetic algorithm are also used as learning techniques the same purposes (Du, Sun, 2006).

Applications in Food Quality Assessments and Classifications

Computer imaging systems can be used for sorting products, detecting defects, identifying internal and external characteristics of foods and inspecting food production equipment, etc. There are a wide range of applications for computer aided analysis systems and their popularities continuously increase. Because of increasing popularity and applicability, some food quality and food process applications were presented in this review.

Fruits and Vegetables

The external appearance of fresh fruits and vegetables is one of the factors affecting the consumer perception. Because the first examination of consumer is visual for quality features such as freshness, taste, decayed, maturity, it has vital importance how to present food and agriculture products to the market. Computer aided vision systems are considered as new tools which are implemented to meet the quality requirements depending on customers' demands. By this way it is possible to achieve shape classification, defect detection, quality grading and variety classification (Brosnan, Sun, 2004).

Yang et al. (2012) investigated the detection possibilities of faecal contaminations on the surface of Golden Delicious apples using hyperspectral line scan fluorescence imaging and developed a simple multispectral algorithm. A pair of violet red line lights equipped in order to excite the faecal contamination spots on the apples created in different dilutions. The algorithm utilized the four fluorescence densities at four wavebands (680, 684, 720 and 780). It was noted that more than 99% of the faecal spots could detected from the uncontaminated apple areas. It is feasible to use this system on high-speed apple processing line with the purpose of preventing food originated illness for food assurance and reduction of risks. Kim et al. (2007) built up a rapid online scanning system which works both with hyperspectral Vis/NIR reflectance and fluorescence in the Vis with UV-A excitation. The system was combined with a commercial apple sorting machine at a processing line speed over three apples per second. Great performance was acquired with a faecal detection rate of 100% (with no false positive) and 99.5% (with 2% false positive rate only) using fluorescence imaging and near-infrared reflectance, respectively. Another hyperspectral imaging system was developed by ElMasry et al. (2008) for detection of bruises on McIntosh apples in a recent study. The spectral region of the system was between 400 and 1000 nm however three wavelengths in the near infrared region (750, 820, 960 nm) gave promising results. It was noted that the bruised apples were successfully detected from the sound apples. Being different from previous studies, the system could recognize early bruises created just 1 hour before and could also recognize even the apples have different background colours (red, green or reddish).

Wang et al. (2011) examined the possibilities of detecting external insect infestation in jujube fruit. They utilized a hyperspectral reflectance imaging approach in the spectral region of 400–720 nm although three wavelengths (500, 650, 690 nm) gave the maximum discrimination. The results revealed that all of the intact cheeks and calyx-end regions classified correctly. More than 98.0% of the undamaged jujube fruits and 94.0% of the insect-infested jujube fruits were correctly identified and the overall classification success of the system was about 97.0%.

Taghizadeh et al. (2010) focused the evaluation of shelf-life of fresh white mushrooms (*Agaricus bisporus*) stored in different packaging materials. At the end of the study they managed to determine superiority of packaging materials compared to each other using hyperspectral imaging system. They were able to reduce the colour inspection time less than 1 minute without touching samples and also determined the distribution of quality in a batch which is not possible with classical colourimeters.

Due to hardness of selecting slight rottenness on the mandarins, workers carry out the issue manually under ultraviolet illumination. Often the rottenness is happening by infection of *Penicillium* sp. fungi. Unless the organisms are eliminated, they can spread to a large number of fruits and can cause great economical loss. Gómez-Sanchis et al. (2008) investigated the possibility of detecting fruits that were rotten due to *Penicillium digitatum.* The study aimed both preventing workers against the harmful effects of UV lights and detecting troubled mandarins in a faster and more accurate way. Therefore they used a machine vision system, without any UV radiation illumination. The rate of success for sorting rotten mandarins from sounds was above 91% and this result indicated that the hyperspectral computer vision system was able to detecting damage caused by *Penicillium digitatum* in mandarins.

It is also possible to establish some internal quality attributes of fruits and vegetables without damaging via using computer vision system. A study conducted by ElMasry et al. (2007) indicated that moisture content, the total soluble solids and pH value of strawberry fruits could be determined by hyperspectral imaging in and near-infrared (400–1000 nm) regions with high correlation coefficients. Moreover, they conducted a texture analysis on the images based on grey-level co-occurrence matrix (GLCM) in order to determine the ripeness level of the strawberries. High classification accuracy of 89.61% was accomplished using the GLCM parameters. More recently, soluble solid content and titratable acidity, which are two of the internal quality properties indicating tomato flavour, determined by Flores et al. (2009) using near-infrared reflectance spectroscopy. The technique allows the examiner to analyse each tomato sample individually without destroying both in on-set and on-line systems and could accurately estimate tomato quality parameters. Fernandes et al. (2011) examined the determination of anthocyanin concentration of whole grape using hyperspectral imaging and neural network. Hyperspectral data was obtained from whole Cabernet Sauvignon grapes in the reflectance mode between the wavelengths from 400 to 1000 nm. At the end the study, they found a squared correlation coefficient of 0.65 between the estimated and traditionally analysed results.

One of the other techniques used for computer imaging is using thermal cameras. The thermal imaging method developed by Stajnko et al. (2004), in order to predict the number of apples in the orchard and measuring their diameter, brought out successful results. Coefficients of determination (R^2) were calculated from 0.83 to 0.88 for numbers of apples and were 0.68 to 0.70 for diameter of apples between manually measured and estimated numbers. It is noted that the rise in both of the correlation coefficient number were seen during the ripening period. Gan-Mor et al. (2011) utilized thermal imaging systems with the purpose of optimizing the high-temperature surface heat treatment which was employed against *Sclerotinia sclerotiorum* (Lib.) de Bary fungi in carrot packaging process. Excessive heating causes damages and discolouration whereas insufficient heating results in incomplete disinfection. The aim of the system was monitoring the process, regulating heat steam level, and gaining uniformity over carrots surface segments using a short, 3 s steam treatment. Reduction around 60–80% in post-storage phytotoxic colour change was achieved and sensitivity to post-storage soft rots by *Sclerotinia sclerotiorum* was lowered significantly.

Meat

Computer imaging systems are also applicable in the meat industry. These systems can be used for defining some quality features of fresh beef meats like surface colour, pH and tenderness, contaminants.

Park et al. (2011) successfully managed to detect small amount (about 10 mg) of faecal and ingesta contaminants on poultry carcasses by using real-time hyperspectral imaging system. This additional process was found not to affect real time process duration which was about 140 carcasses per min. ElMasry et al. (2012) determined some quality characteristics (pH, colour and tenderness) of fresh beef with traditional methods and modelled with their matching spectral values, gained by a hyperspectral imaging system in the near-infrared spectral region (900–1700 nm), using partial least square regression. However, the authors of this study stated that more samples were required for better examination and more robust modelling, and reported that the presented sampling was just enough to take satisfying results. Good performances were achieved and it was explained the system could be useful, reliable, non-destructive and rapid alternative to traditional analysis methods. Potential applicability under the visible light is one of the other advantages of the technique. Recently great accuracy was found in the study by Feng et al. (2013) where determination coefficients (R^2) of *Enterobacteriaceae* bacteria on chicken fillets were 0.89, 0.86 and 0.87 for the three wavelengths of 930, 1121 and 1345 nm, respectively, using near-infrared hyperspectral imaging analysis. The superiority of the imaging techniques compared to traditional analyses methods is that they allow displaying distribution of the analysed properties. On-line inspection of poultry carcasses is also feasible.

Other Foodstuff and Applications

Mokhtar et al. (2011) studied the in-line detection of crumbling, in-homogeneousness, unevenness in size, cracks and glutinous on the surface of pasta (stick together). Flat LED light source, a CCD camera were used and a production line monitoring system was developed accepting process analytical technology basis using a microcontroller of camera. The error in determination of stickiness, crumples and unevenness in size were 1%, 5% and 13%, respectively. It was also noted that being glutinous was easily detected.

Abdullah et al. (2000) investigated the possibilities of classification of muffins with respect to their colour. A classification algorithm used for separating dark from light samples using pre-graded and ungraded muffins. Classification correction rates were 96% of pre-graded and 79% of ungraded muffins when compared with visual inspection.

A computer vision system, developed by Kılıç et al. (2007) examined the classification of beans using artificial neural networks. Size and colour were the parameters for the application. Firstly, length and width were measured both by a calliper and the system. High correlation (r=0.984 and 0.971 for length and width, respectively) was determined between the results. Secondly, the classification of beans into five classes was performed by human inspector and system. There were rate of correction of classify such that 99.3% of white beans, 93.3% of yellow–green damaged beans, 69.1% of black damaged beans, 74.5% of low damaged beans and 93.8% of highly damaged beans sorted correctly. The overall correct classification rate obtained was 90.6%.

Shafiee et al. (2014) developed a system for characterization of honey based on colour. Estimation of ash content, antioxidant activity and total phenolic content were intended using artificial neural networks. The correlation coefficients of predictions were 0.99, 0.98 and 0.87 for ash content, antioxidant activity and total phenolic content, respectively. They were found to be very promising. These results showed that such a system could effectively applicable for the industry.

The computer imaging systems can also be implemented in dairy industry. For instance a study was conducted by Fu et al. (2014) to determine melamine contamination in milk powder by a near-infrared hyperspectral imaging system. Three different spectral similarity analyses were performed to identify melamine particles in various concentrations. The study results revealed that system could detect melamine at very low concentrations (from 0.02% to 1%) in milk powder and authors also reported their providences that the method had potential to identify some kind of chemicals. Huang et al. (2014) aimed to obtain total chemical information of a milk powder mixed with three different components ($ZnSO_4$, lactose and melamine). In this study near-infrared micro-imaging system was employed to acquire information and distribution of three target components. The correlation coefficients for detection of melamine in various concentrations (30%, 10% and 5%, w/w) were all over 0.9. The success of determination was decreased and being less than 0.61 with reducing melamine concentration (1%, w/w), although this compound was still detectable. Encouraging results were also obtained for $ZnSO_4$ and lactose. In a previous study Eskelinen et al. (2007) investigated the possibility of quality and process control of Swiss cheese. 3D ultrasound imaging technique was conducted in order to acquire images. Cheese-eyes (gas holes), cracks and bulk cheese matrix could be distinguished with high success.

One of the newest technology was studied by Lee, Lee (2014) is based on using terahertz (THz) imaging. The inspection of foreign materials like metal objects in food products is commonly performed by X-ray radiation or ultrasonic detectors. If the food contains active compounds such as lactobacillus or fungus, there are concerns of radiation damage and residual radiation in specific materials. On the other hand, being free from radiation hazards, ultrasonic technology, especially low photon energy, is convenient for food applications. By improving resolution quality with a high-power gyrotron, a THz detector, and optical mirror system, a 0.8 mm resolution was achieved using a 0.4 THz transmission image. Consequently, it was demonstrated that it is possible to inspect foreign objects even in packaged food products using this technique in a non-destructive and radiation-free way unless the packaging material contains metal elements like aluminium (Lee, Lee, 2014).

Imaging systems are not used just for food and agriculture products and also used food processing surface. In their study Jun et al. (2009) tried to determine microbial biofilms on the surfaces in contact with food and agriculture products. They used a hyperspectral fluorescence imaging system. Maximum emission was identified at approximately 480 nm. The results indicated that it is possible to detect presence of microbial biofilm on the different surfaces such as stainless steel, polypropylene, formica and granite.

Conclusions

This paper represents basic knowledge about computer image analysis systems used in the food industry including general step of imaging processing and analyses with some examples on applications.

Computer imaging systems make possible to estimate some internal and external quality parameters and to enhance food and agriculture products safety and quality. Automated, rapid, hygienic, non-destructive and objective inspection can be accomplished with these systems. Having wide range of application field, being cheaper and usable in-line processes and their flexibilities make imaging systems more attractive.

It seems that further improvements in technology and continued development in computer imaging technology will bring out higher implementations understanding of these systems and allow providing growing needs of the food industry.

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