Journal of Food Engineering 128 (2014) 146–156

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

On-line automatic detection of foreign bodies in biscuits by infrared thermography and image processing

L. Senni [a], M. Ricci [a,*], A. Palazzi [a], P. Burrascano [a], P. Pennisi [b], F. Ghirelli [b]

[a] University of Perugia, Polo Scientifico Didattico di Terni, Italy
[b] Colussi S.p.A., Milano, Italy

ARTICLE INFO

Article history:
Received 30 August 2013
Received in revised form 29 November 2013
Accepted 12 December 2013
Available online 25 December 2013

Keywords:
Foreign bodies detection
Infrared thermography
Non-destructive evaluation
On-line detection

ABSTRACT

The on-line implementation of a Thermography Non-Destructive Testing method for the detection of inner contaminants and foreign bodies in biscuits is presented. The procedure exploits an image processing algorithm developed to be applied to the thermograms provided by an infrared camera and it entails an automatic defect detection protocol. It is shown that the proposed procedure allows the automatic on-line detection of most of the defect types considered. To achieve this result, preliminary off-line and on-line tests and their statistical classification analysis were performed. The off-line measurements consisted in the acquisition of temporal sequences of thermograms collected at the exit of the oven during the cooling process of biscuits. The processing is focused on the comparative analysis of the thermal emissivity of both foreign bodies and of biscuits decay curves. Benchmark defects were inserted in the on-line products. The statistical classification analysis was executed on thermograms acquired on these benchmarks and it was aimed to the individuation of an automatic foreign body detection algorithm.

1. Introduction

Food quality and safety assessment are major concerns in the food industry. To satisfy the consumer demand for high quality products, producers and processors use ever improving procedures to guarantee food products safety and prevent the presence of foreign bodies. This quality pursuit involves several control steps along the entire food production chain; nevertheless, in spite of the increase both in the quality assurance efforts and in control technologies, some contamination can occur in the final product. This can be the case of mass production of bakery products: although the whole production is monitored, from the control of raw materials (typically mechanical) to the monitoring of all the intermediate production steps, some foreign bodies can be found in the products purchased by consumers. Having available techniques able to detect impurities or inhomogeneities, products with defects can be ejected out of the production line by means of mechanical systems, thus ensuring both a high-quality and a high-safety for end-consumers. In this framework, the present work deals with the detection of foreign bodies in baked products, in particular in biscuits produced by *Colussi Group*, by means of an Infrared Thermography (*IRT*) based system.

1.1. Infrared thermography in food inspection

IRT was first proposed some decades ago but, due to the low sensitivity of *IR* sensors available at that time (low resolution and high cost) only in the last years it has found effective application. Nowadays, *IRT* food inspection is an emerging technique: different applications and processors relying on the analysis of the *IR* spectrum emitted, reflected, absorbed or diffused by samples are now available (Osborne and Fearn, 1986; Graves et al., 1998; Kim et al., 2001; Meinlschmidt and Maergner, 2003; Brosnan and Sun, 2004; Gijsbertsen et al., 2004; Lee et al., 2008; Gowen et al., 2010; Vadivambal and Jayas, 2011). Depending on the frequency ranges, *IR* spectrum usually subdivides in near (0.75–2.5 μm), short (1.4–3 μm), mid (3–8 μm), long (>8 μm) and extreme wave (15–100 μm) regions and, for each range, different sensor technologies have been developed and specific *NDT* applications were tailored. Among all the possible ones, the most diffused in food inspection are Hyper-spectral *IR-NDT*, Active and Passive *IR-NDT*. Hyper-spectral *IR-NDT* is particularly suitable to evaluate the quality of fruit, vegetables, seeds, flour, etc. and it exploits frequency analysis of the *IR* spectra to assess the chemical composition of materials; in general hyper-spectral *IRT* works on the near and the short ranges and the sensors collect the radiation reflected or diffused by the samples (Kim et al., 2001; Gowen et al., 2007; Qiao et al., 2007; Del Fiore et al., 2010). Hyper-spectral *IR-NDT* is also possible in the mid range, but the sensors are very expensive and then not suitable for on-line installation. If the chemical

* Corresponding author. Tel.: +39 0744492937.
E-mail addresses: luca.senni@unipg.it (L. Senni), marco.ricci@unipg.it (M. Ricci), alessandro.palazzi@gmail.com (A. Palazzi), pietro.burrascano@unipg.it (P. Burrascano), Paolo.Pennisi@colussigroup.it (P. Pennisi), federico.ghirelli@colussigroup.it (F. Ghirelli).

0260-8774/$ - see front matter
http://dx.doi.org/10.1016/j.jfoodeng.2013.12.016

identification of foreign bodies is not needed, thermal imaging techniques can be used assuring a relaxation of the set-up complexity.

In Active *IR-NDT* the sample under test is stimulated by a proper thermal excitation and thermal images are collected in a determined time interval in order to reconstruct the time–temperature curves of the sample. By analyzing the behavior of such curves for any image pixel, inhomogeneities, flaws and foreign objects can be individuated even in the case of internal defects (Maldague, 1993; Baranowski et al., 2009; Ginesu et al., 2004; Lee et al., 2008). Different typologies of excitation can be utilized depending on both the material investigated and the desired sensitivity: pulsed excitation, phase-locked excitation and pulsed-locked excitation are commonly used (Maldague and Marinetti, 1996; Mulaveesala and Tuli, 2006; Pallav et al., 2009; Tabatabaei and Mandelis, 2011; Ghali et al., 2011). On the contrary, passive *IR-NDT* collects thermograms without exciting the sample under test and exploits image processing to perform the analysis on a single-frame or a small sequences of frames. The measurement set-up is quite simple but it usually suffers from a lack of Signal-to-Noise Ratio – *SNR* – since the thermal contrast between defects and background cannot be enhanced by the heating stimulus.

Generally, whatever technique is employed, it is difficult to precisely assess the pixels temperature in complex structures, as the biscuits are in this sense, because the variations of the pixels intensity can be due to several factors such as differences in the local temperature, differences in the local emissivity, distortion of the sensor optics, and all the problems lying in image acquisition. Nonetheless, discontinuities in the thermograms can be usefully exploited to accomplish the defect detection task (Meinlschmidt and Maergner, 2003; Ginesu et al., 2004; Omar et al., 2005; Mulaveesala and Tuli, 2006; Bukowska-Belniak et al., 2010). In the present application, one of the major problems is represented by the requirement of working on-line; indeed the biscuits here considered are produced at relatively high rate: depending on the biscuits size, the conveyor belt moves at ≈20–30 cm/s and, for a coil width of 1 m, about 30–60 biscuits/s have to be analyzed. For such inspection rates, Hyper-spectral or Active *IRT* could be very demanding while, on the contrary, Passive *IRT* can fit with the constraints. At the same time, passive *IRT*, as said, generally suffers from low contrast between defects and background and, when the differences in the pixel intensity are comparable with the image noise, a thermal stimulus is needed, either heating or cooling, to generate a gradient. Fortunately, the production line offers a thermal excitation that does not affect food integrity: the oven used for the cooking process becomes our "ad hoc" heating stimulus and, by acquiring thermograms during the subsequent cooling process at the output of the oven, sufficient sensitivity can be obtained to detect foreign bodies both in the surface and in the bulk of a biscuit. To accomplish this aim, it is therefore of utmost importance to individuate the optimal distance from the oven at which the images must be collected in order to maximize the *SNR* of the thermograms. Unfortunately, such position cannot be predicted by theoretical models or by numerical simulations, since the mathematical description of the heating and the subsequent cooling processes are not available. The cooking process is indeed complex: the oven is approximately 100 m long and inside it the temperature follows a spatial profile optimized for the characteristics of the type of biscuit processed at that moment. Moreover, during cooking, the ingredients of the biscuits undergo to several chemical–physical transformations (Maillard reactions, water evaporation, etc.), and it is not trivial to mathematically model the heating stimulus provided by the oven to the single biscuit.

At the same time, in order to measure the cooling of the biscuits along the production line, one has to move the thermocamera to follow the sliding of the conveyor belt or alternatively to use an array of thermocameras at fixed distances. Both the methods are quite demanding tasks.

For these reasons, the experimental activity consisted of two main parts: in a preliminary phase, a temporal analysis of the cooling curves of biscuits was performed by using a static oven; subsequently, by taking advantage of the information provided by the aforementioned analysis, the on-line installation and the final measurement procedure were developed. The off-line experiments allowed a first evaluation of the complexity of the defect detection task, mainly hampered by the complex texture of the biscuits and by environmental noise in the proximity of the oven. They also provided at the same time useful information to develop the image processing algorithm and to define the optimal on-line set-up. The on-line experiments involved a huge data acquisition campaign aimed at optimizing the image processing algorithm and at executing a statical analysis on benchmark defects in order to implement an automatic foreign bodies detection procedure.

The paper is organized as follow: Section 2 and its subsection elaborate on the off-line measurements and experiments, in particular Section 2.1 illustrates the result of the preliminary analysis. Section 3 deals with the on-line installation and the relative subsections describe the hardware and software set-ups respectively; Section 4 reports the experimental results of the automatic foreign bodies detection procedure together with an analysis of its performances and drawbacks. Subsequently Section 5 draws some conclusions and discusses perspectives for future developments.

2. Off-line experiments: set-up and results

The experimental set-up used to perform thermographic time-series measurements consists of a thermal heating unit (oven), an infrared camera (FLIR SC-620) and a computer system which enables image processing and recording. The camera sensor is an uncooled microbolometer sensible to IR radiation in a wavelength region from 7.5 to 13 μm and 60 mK of temperature resolution, acquiring 640 × 480 pixels images.

In order to make the preliminary off-line measurements, foreign bodies (stone, piece of glass, piece of plastic, wood, paper, textile fiber) were inserted on some biscuits dough (Petit type) collected from the production line before cooking, see Fig. 1. Contaminants were located at different depths below the back surface and their dimensions varied between 1 mm and 3 mm. The samples were then cooked in the static oven of the Colussi S.p.A. R&D laboratory for 6 min at a temperature around 250 °C. These parameters assured that biscuits at the output of the static oven resulted to be very close to the ones coming out from the on-line oven. After baking, while biscuits were cooling down to reach the room temperature, thermal images were acquired every 10 s for about 30 min, corresponding to 170 images collected. An image of the baked samples are reported in Fig. 2, where it is evident that the defects are not visible from the top view of the biscuits.

By looking at the thermal image sequences, most of the foreign bodies can be detected by eye inspection of the IR images; nevertheless, the development of an automatic image processing algorithm capable of automatically detect the defects proved to be not trivial. The main issues faced are those deriving from the control of environmental parameters such as thermal reflections, external thermal contributes, and those deriving from the biscuits geometry: holes, imperfections, surfaces irregularities.

In order to study the time behavior of each point of the thermal image, data are organized as follows: a data cube is created, where x and y are the spatial coordinates of the pixels of the IR images, and the time sequence is on the third dimension. Then each cube has about 640 × 480 pixels image in the spatial axes and 170 consecutive frames in the time axis (one each 10 s).