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Quality Control of Hazel Nuts Using Thermographic Image Processing

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Abstract

This paper describes some new approaches to the quality inspection of hazels, analyzing thermographic images. On the one hand we present a quality inspection system checking large amounts of hazels carried on a conveyer belt and on the other hand a system, which permits a more detailed quality classification controlling single objects. We emphasize the characteristic properties of thermographic images, which lead to the kind of image processing algorithms we use. Thresholding and texture analysis algorithms, as well as fuzzy logic for the classification of single objects are applied.

1 General instructions

Each year thousands of tons of hazels are processed or prepared for processing by the sweets industry. The procedure includes cleaning and classifying with respect to the quality of the hazels as well as the removing of foreign bodies. The detection of foreign bodies rests on mechanical, optical and ultrasonic methods. These techniques enable the detection of foreign bodies, which differ from hazels with respect to the mass, the colour or the surface density. By using these methods a large portion of foreign substances is detected, but unfortunately there is still a quality problem for the remaining ones. Moreover, there are also approaches, using the X-ray technology, but due to the radiation exposure they are often undesired for safety reasons. Within the framework of a research project, possibilities were investigated using infrared thermography for the online detection of foreign bodies in food and particularly in hazels. The different thermal behaviour of different materials is used to detect foreign bodies. A thermographic camera produces images that represent the thermal radiation of material in gray values. The food under investigation is slightly heated and then after a fixed period of cooling time the thermographic camera takes an image. The differences in the cooling behaviour appear in different gray values in the thermographic images. This property yields the choice of the image processing algorithms. In the first attempt algorithms resting exactly on the above mentioned characteristic of the gray level difference between the hazels and the foreign bodies were analyzed. Furthermore texture analysis algorithms were applied in order to find defects in the texture consisting of a high density packing of hazels.

As an alternative approach, individual nuts were inspected in order to account object oriented features instead of measuring global properties of large quantities of hazels.

2 Thermography

Studies concerning the possibility of detecting foreign bodies in food by using IR-thermography were reported by Meinlschmidt, Maergner et al. [4, 5, 6]. The results show that one obtains images with highest contrast, using a flash light to heat the hazels. Furthermore they discovered considering the cooling behaviour of both hazels and typical foreign bodies that the most advantageous time to inspect the hazels is about one or two seconds after the heating pulse. The thermographic camera used for the experiments is a Thermosensorik-System CMT 384 M [3]. The camera uses a matrix of 384 x 288 HgCdTe (CMT) stirling cooled infrared sensors, capable of detecting middle infrared radiation in the range of 3,4 – 5,2μm. The temperature resolution is < 20mK (NETD) and each pixel has a 14 bit resolution. The pixel pitch is 24 x 24 μm and the maximum full frame rate can be up to 130 Hz.

3 Image processing algorithms

In the following the image processing algorithms are described in detail, which were used to detect foreign bodies or nuts of bad quality in a thermographic image made of slightly heated nuts on a conveyer belt. Figure 1 shows an example of a photo and the corresponding thermographic image.

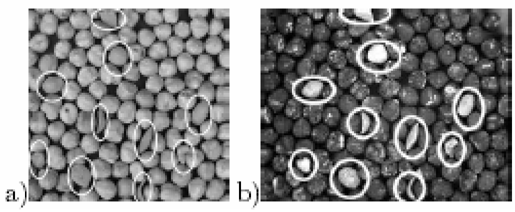


Figure 1: a)Gray level photo of hazels with foreign bodies; b)Thermographic image captured 0.25s after heating the hazels with a flash
(stones and nutshells are marked with a circle)

3.1 Preprocessing

The first preprocessing task is to correct dead pixels, which are defined as those sensor elements in the thermal detecting matrix that behave in an unpredictable way (about one percent of total pixels for new systems). The dead pixels have fixed positions on the detector surface. Thus knowing the positions the missing values may be replaced by neighboring values. As the perturbation is almost like salt and pepper noise, also a median filter yields good results. Another problem, typical for thermographic images is shading, as a result of inhomogeneous temperature in the surrounding area. This effect can be corrected subtracting the image filtered with a low pass filter with a pretty low cut-off frequency.

3.2 Tresholding

The characteristic property of the significant gray level differences between the hazels and the foreign bodies suggests using a gray value threshold of the images to detect foreign bodies. The major task consists in finding an appropriate algorithm for the determination of a threshold. As usual the histogram of the images provides the basis of these algorithms.

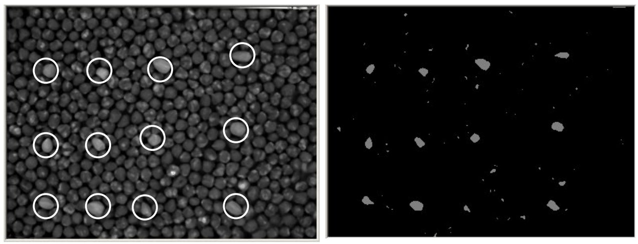
In the test material the portion of foreign bodies between hazels amounts to less than one percent. Hence the histogram shows a strong accumulation of gray values, representing the hazels and only a small tail, representing the foreign bodies. Well known automatic threshold detection algorithms like the method from Otsu [2] do not work properly for this kind of gray value distribution, because the histogram is of an unequal distribution. Moreover in many cases there is only one class of gray values, because there is no foreign body in the image under inspection. Obviously, the algorithm should detect foreign bodies. But on the other hand and particularly in the case of non-existence of foreign substances the algorithm should not identify nuts as foreign bodies. By using the described method of thermography experiments showed us that almost all foreign bodies have much higher (brighter) gray values than the hazels. This is called the higher level case. But there is also the possibility that some foreign bodies have lower gray values than the hazels that is the lower level case. In this paper an algorithm is described, which detects the foreign bodies in the higher level case. With some simple modifications the algorithm can be modified to detect the foreign bodies in the lower level case.

In order to determine the threshold, methods of first order statistics are used. The threshold T is given by

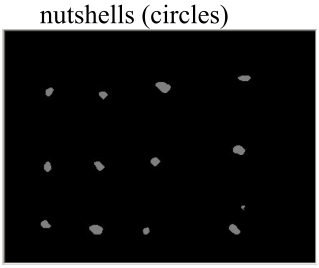
$$T = R + \alpha * \sigma \quad (1)$$

where R is the mean, the median, or the maximum of the histogram, σ the standard deviation, and $\alpha > 0$ a constant value, which has to be adjusted for each type of hazels, for example roasted or fresh ones. Experiments were conducted with roasted hazels and some authentic foreign substances, supplied by a chocolate manufacturer. These experiments indicated that the time of the measurement plays a decisive role. If the hazels are tested immediately (up to two seconds) after the heating flash the hazels surface appears very inhomogeneous so that a separation of nuts and foreign bodies adapted only from the pixel gray value is not possible. Images which are taken five seconds and later after the flash are much more homogeneous but some foreign bodies can not be detected any more. Therefore it is recommended to choose an earlier point in time and to post-process the binary image. Then, as there are not whole nuts but only small parts of the hazels detected, one can select real defects by the object size. The standard method of morphologic opening is used to delete very small particles. Figure 2 shows an example. Fig. 2a shows the thermographic image, fig. 2b the image after applying the automatic threshold, and in fig. 2c the final result after the post-processing can be seen. In this example all nutshells are detected and only one hazel is detected as foreign body.

This detection method requires closely packed nuts as too many background pixels in an image would affect the result negatively. Furthermore the temperature of all nuts under investigation has to be the same as the temperature differences used to detect foreign bodies are very low. All experiments described here were carried out in an experimental environment. Within an industrial environment it is more difficult to keep the above mentioned conditions. More statistically relevant results have to be done within an industrial environment.



a) Hazels and hazels with nutshells (circles)   b) Automatic threshold



c) Final result after post-processing

Figure 2: Examples showing results of the automatic threshold.

3.3 Texture analysis

Instead of assessing single pixels for classification, texture analysis includes the pixel neighbourhood to the classification process. There are two main approaches, to describe textures, the statistical and the structural approach. In this work, statistical texture models are used, because the arrangement of hazels on a conveyor belt is not subject to a defined rule, which would justify a structural texture model. Due to the characteristics of the images to be treated, first order statistics are used, to describe the texture. Again the histogram is considered. In fact not the histogram of the whole image is studied but of smaller, overlapping sub-images. If the sub-images are of sufficient size, each of these is a representative of the texture.

Thus the histogram should be almost the same for all these sub-images. To detect defects in a textured image, the histograms of the sub-images are compared with a prototype histogram, which is obtained from images without defect. In order to compare two histograms, firstly the rank order function is determined from the histogram.

The rank order function enables us to define a distance measure that weights the differences proportionally to their distances from the mean value, which is important for our purpose [1].

Let *H(g)* denote the histogram of the image $I(x,y)$ $g_i, i \in [0...N-1]$ with M pixels. The rank order function $R_H(z)$ is defined as the ordered ascending sequence:

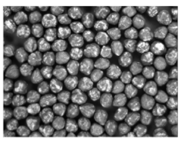
$$R_H : [1,...,N] \rightarrow [0,...,M] \qquad (2)$$

By means of this function, the distance between to histograms H_1, H_2 as the sum of the squared differences, is defined as:

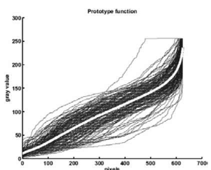
$$D_{sqd}(H_1,H_2) = \sum_z (R_{H1}(z) - R_{H2}(z))^2 \qquad (3)$$

Now the texture can be described by a rank order function. First of all a prototype function has to be calculated, which describes the texture without any defect. Subsequently the image without defects is partitioned into sub-images and the rank order function for each sub-image is calculated. As a prototype the rank order function R_v is used that shows the minimum mean distance from all the sub-image rank order functions.

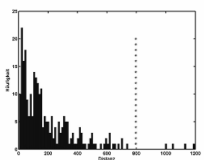
The variance of the distances to the prototype function in the undisturbed texture is used for the decision, if a sub-image contains a defect or not. Again a threshold *T*, using the formula (1), is defined in order to classify the sub images as good or not. To detect only local defects in the texture, before processing an image, the gray level is transformed to the same mean as the prototype. The image under inspection is partitioned into sub-images of the same size, the rank order function for these sub-images is determined, and the distance to the prototype function is calculated. If the distance exceeds the threshold, the sub-image is marked as defect. Experiments conducted with the above mentioned material show that the described method is capable to detect foreign bodies between hazels. Compared to the threshold method presented before it turns out that the rank order functions are less sensitive to the inhomogeneous surface of a nut. Figure 3 shows an example for the creation of the prototype function. In Figure 4 an example of the detection result can be seen. Important for the detection result is the size of the sub-images. The best results were achieved choosing sub-images having about the same size as a nut. Considering this result it has to be realized that not the texture, formed by several nuts, is analyzed but the texture of a single hazel. Among others also this is a reason to analyze single nuts (see section 3.4)



a) Prototype image



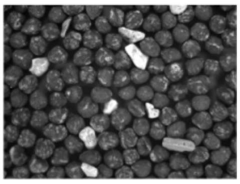
b) Prototype function as mean of the sub-image rank order functions



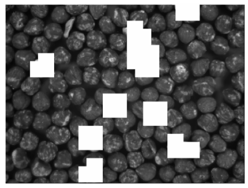
c) Distances to the prototype functions

Figure 3

As mentioned before the tests were carried out within an experimental environment in the laboratory.



a) Image with foreign bodies



b) Defect detection

Figure 4

3.4 Analysis of single objects

The experimental setup for the measurement of single objects includes a bar the hazels are separately rolling on. In the upper part of the bar the hazels are heated by two IR-radiators mounted parallel to the bar. The measurement takes place in the lower part of the bar. As the nuts are rolling, two essential advantages arise. The nuts are heated nearly all around and in the same way they can be observed from several views. For some examples showing different objects see figure 5.

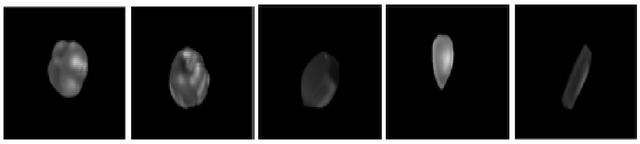
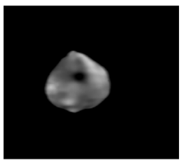


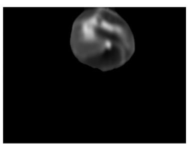
Figure 5: Thermographic image of rolling objects. From left to right: good hazel, foul hazel, hazel with nutshell, peace of a nutshell, stone

Among the feature (implicated by the thermography) mean gray value, also the variance of the gray values is considered. In particular foul nuts and nuts with insect stings show conspicuous dark spots, and the range of appearing gray values is much broader than for good nuts. Dark spots can be detected by thresholding the image. As the background in all images is nearly black a bimodal histogram follows. Choosing the threshold by the algorithm of Otsu[2], the dark spots are ranged to the dark / background class. Figure 6 shows two example for this kind of defect.



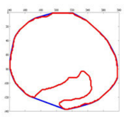
a) Nut with insect sting

b) Thresholding result



c) Foul nut

d) Thresholding result



e) Convex hull and object contour

Figure 6

Also the texture feature obtained by the rank order functions show good discrimination performance. Moreover the measurement of single objects permits to analyze the shape of the objects. As hazels normally are rotund, the length to width proportion constitutes a feature to distinct nuts form stones or pieces of nutshells. Also the surface area of hazels ranges in definable limits. Evaluating the following features,

- Mean gray value
- Variance of the gray values
- Rank order function distance to a prototype
- Object area
- Difference between the area enclosed by the convex hull and area of the binary object
- Length to width proportion

a fuzzy classification system [5] was implemented. Each feature is described with a membership function, taking into account only feature data from good hazels.
The features are combined with two simple rules. A good hazel confirms all constraints. If one of the measured feature values is out of range, the object is classified as bad object (foreign body or foul nut). This classification system was proofed with some labeled objects. Figure 7 shows the promising classification result. All foreign bodies, stones, pieces of nutshells, and whole hazels with nutshell are detected. Even the main portion of foul nuts or nuts with insect stings is detected, but there are still some wrong classifications. Nevertheless it can be acknowledge that this is a promising first step, which must be verified by further tests with a relevant amount of test objects.

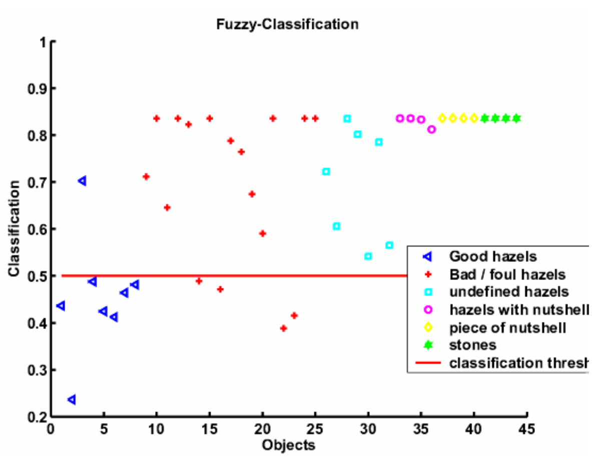


Figure 7: Fuzzy classification result

4 Discussion

We presented three different approaches for the quality inspection of hazels using thermography. The former two are suitable for the investigation of large quantities of hazels carried on a conveyer belt.
In the case of complying the before mentioned requirements a satisfactory detection of foreign bodies can be achieved.

The third approach, the analysis of single objects, permits a more detailed quality classification. This kind of inspection allows not only detecting foreign bodies but also nuts of bad quality, which in particular is of great interest for the production of high quality products as sweets or chocolate.

Actually we are working with optimizing the fuzzy based classification system. For this purpose we are using more different features, e.g. texture describing features but we are also modifying the rules used to combine the membership functions. The aim of these modifications is a more detailed classification of nuts into different quality classes additionally to the detection of foreign bodies.

So far both systems are tested only under laboratory conditions. To provide the evidence of the presented methods extensive tests under industrial conditions have to be carried out.

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