NIR

Machine vision combined with hyperspectral NIR to guarantee food safety

Swiss company, QualySense - has developed a robot to inspect oats for gluten-free labeling of breakfast cereals

Health claims relate a food substance to the reduced risk of a disease or to a health-related condition, and depend on the quality of the raw materials. Here we focus on ready-to-eat 'gluten-free' breakfast cereals.

Some cereals are gluten-free by nature. However, they can be contaminated with gluten that is carried by grains such as wheat, barley and rye, this can happen at any time.

For this reason food processors must ensure high purity levels of the end products. This is achieved by running accurate, lengthy and frequent inspections on selected samples to identify gluten contamination.

The presence of gluten requires additional processing costs and may lead to serious legal claims. Today trained personnel inspect samples to identify impurities that are generally below two percent, a procedure that is lengthy and affected by subjective biases and low repeatability.

The manual visual inspection is based on shape and color features but the variation of these parameters is often small enough to challenge even the most trained inspectors as well as detection technologies based on Machine Vision. In fact, several researchers have made attempts to solve this problem using Color Images, which resulted in non-reliable methods.

QualySense has developed a proprietary high-speed single kernel analyser, the QSorter Explorer and investigated the possibility of combining Machine Vision with hyperspectral NIR. Color images and infrared spectra between 900 nm and 1700 nm were acquired, preprocessed and classified with various algorithms.

As a result, a method based on the detection of gluten with NIR combined with shape and color assessment enable the QSorter Explorer to reach classification accuracies higher than 95 percent and with very low repeatability errors.

This method has been successfully tested and adopted by leaders of the gluten-free industry.

Methods for gluten monitoring

In the USA and in Europe a product is labeled 'gluten-free' if, according to the law, it contains less than 20 ppm (part per million) of gluten.

Figure 2: The QSorter Explorer

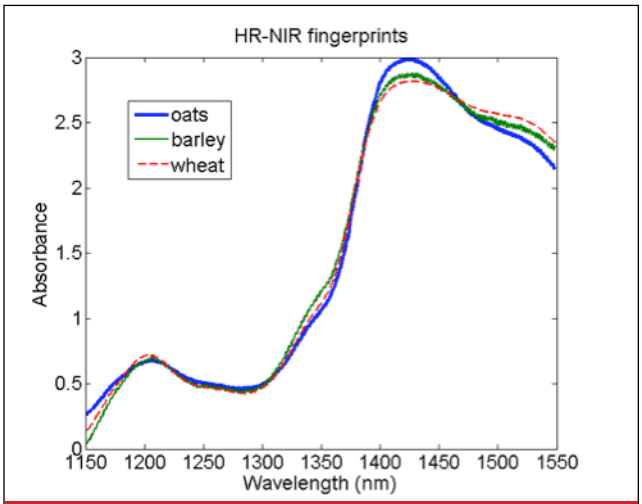

Figure 1: NIR spectrum for oats, barley and wheat

Food processors must ensure the high purity level of the gluten-free cereals by running accurate and frequent quality inspection activities on selected samples during processing. These inspections aim at identifying wheat, barley and rye or, in other words, the gluten contamination.

If the sample does not meet the 20 ppm requirement then the gluten-free cereal lot must be cleaned. The cleaning process is made by means of mechanical equipment such as screens or sieves.

Today, trained personnel inspect manually samples of several thousands of kernels before and after the cleaning process, the inspector must: (a) Identify all types of contamination; (b) Separate them into classes (i.e. barley, wheat, and rye) and (c) compile a quality inspection report.

Table 1: Average of several experiments

	Oats detection		Contaminants detection	
	Accuracy [%]	Repeatability [%]	Accuracy [%]	Repeatability [%]
Low threshold	96.65	97.82	98.73	98.39
High threshold	92.14	96.78	99.97	99.90

Table 2: Results of a specific experiment

	Oats			Contaminants		
	Detected amount [kernels]	Real amount [kernels]	Accuracy [%]	Detected amount [kernels]	Real amount [kernels]	Accuracy [%]
Low threshold	1406	1438	97.37	5	6	99.93
High threshold	1343	1438	93.39	6	6	100.00

Before cleaning, the inspected material has a level of contamination that is generally below one percent. This process can take up to 60 minutes and it is affected by subjective biases and by low repeatability.

The human repeatability error can be as high as 30 percent. This is very dangerous particularly with samples that contain a gluten level close to the legal requirement (20 ppm) because they may be considered “gluten-free” when in fact they are not.

Alternatively, gluten can be measured with qualitative tests such

as ELISA R5, ELISA Sandwich, PCR whose detection limit is between 5 ppm and 10 ppm or with quantitative methods based on mass spectroscopy whose detection limit is in the range of a few ppm.

These tests that require the samples to be milled are time consuming and can be applied only to small quantities (usually in the range of a few grams). This leads to high costs and the need for an increased amount of tests, as well as highly qualified personnel.

Near-Infrared (NIR) measurement principle

Single kernel NIR spectroscopy provides a non-destructive, non-invasive and rapid measurement of the biochemical properties of the kernel, such as its gluten content.

A light beam hits the surface of the kernel, one portion of the incident light is absorbed while another portion is diffusively reflected and measured by a NIR spectrometer.

The detected signal represents the spectral signature of the kernel under analysis. This is used to quantify its biochemical components and to differentiate it from another type (gluten-free kernel versus gluten-containing kernel).

Machine Vision measurement principle

A flashlight illuminates the kernel and a color camera records an image of the grain. The color image is used to extract shape and color features such as length, width, eccentricity, diameter, hue, saturation, and luminance. These physical parameters can be used to further enhance the classification of the kernels.

Combining NIR spectroscopy and Machine Vision for individual kernels

The manual visual inspection of the hand graders is only based on shape and colour features. Unfortunately, the variations of these physical parameters between different types of kernels are often small enough to challenge even the most trained inspectors, as well as detection technologies based only on Machine Vision.

However, from a biochemical point of view, each cereal is characterised by a defined spectral signature (invisible to the human eye), which can be measured by means of a NIR spectrometer.

The NIR spectral signature of a gluten free kernel may appear very similar to the signature of a kernel containing gluten (such as wheat or barley) but the absorbance peaks at 1450 nm and 1550 nm reveal the differences in protein content (Figure 1).

In fact, the classification algorithms use these features to distinguish between kernel types. The robustness of the final predictive analytical algorithm is improved by including also shape and color features that are extracted from the image of each kernel.

This combination greatly enhances the discrimination capabilities of the algorithm and confers a very high repeatability level to the automated quality inspection process.

QSorter Explorer

The QSorter Explorer (Figure 2) is a single-kernel high-speed robot that combines real-time NIR measurements with Machine Vision, thus increasing greatly the selectivity of the quality parameters in the cereals.

It enables a novel and efficient way of inspecting gluten free cereals and measuring their purity or, in other words, how 'gluten-free' they are.

The grains are transported one by one in a fixed orientation and a high-resolution color image and a NIR spectrum is acquired for each one of them. On average, the QSorter Explorer processes and analyses in real-time up to 50 kernels per second.

The QSorter Explorer also includes sorting capabilities, which allow for the physical segregation between gluten-free cereals and other cereals. In this method, the sorting capabilities allow the food quality manager to assess the performance of the gluten-free process with a very high level of confidence.

The QSorter Single Kernel Gluten-Free method is based on the combination of the extracted NIR spectral differences, shape and color parameters. It identifies kernels containing gluten contamination with an accuracy, depending on the set threshold.

A 'low threshold' minimises the false positive (the amount of oats in contaminants) has an accuracy higher than 98.7 percent with a repeatability higher than 98.3 percent.

Whereas a 'high threshold' minimises the false negative (the amount of contaminants in oats) has accuracy higher than 99.9 percent, and repeatability higher than 99.9 percent.

This implies that the error introduced by the hand graders is fully eliminated. In the enclosed tables the detailed results of both configurations are described. The first table is an average of several experiments (Table 1) and the second one is a specific experiment (Table 2).

After sorting, the inspector needs to visually analyse the contamination in order to ensure the very stringent "gluten-free" requirement but also to identify processing equipment is malfunctioning.

The classification algorithm is tuned as such that one output bin of the QSorter Explorer contains as many pure kernels as possible while another bin contains the contaminated kernels and false positives (the gluten-free kernels classified as contaminated).

Considering the very high accuracy of the QSorter detection algorithm, the inspectors can concentrate their analysis only on the bin with the contamination (usually containing around five percent of the total kernels) whilst disregarding the bin containing the gluten-free cereals.

In summary, the QSorter Single Kernel Gluten-Free method drastically reduces the inspection time and eliminates human repeatability error by automating the process.

It detects gluten impurities with very high accuracy, enables the performance validation of processing equipment and represents an effective qualitative method as its detection limit is lower than the ELISA method.

During the past year the method has been successfully adopted by leading food companies in North America and in Europe.

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