IBEX

WHITE PAPER:

DETECTING PLASTIC CONTAMINATION IN CHOCOLATE

IBEX Innovations Ltd.
Registered in England and Wales: 07208355
Address: Discovery 2, NETPark, William Armstrong Way, Sedgefield, TS21 3FH, UK
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Abstract

Plastics and chocolate absorb X-rays to a very similar extent. This makes it difficult for X-ray inspection systems to detect plastic contaminants in chocolate during the manufacturing process when relying on absorption contrast and shape or edge recognition. IBEX technology adds materials sensitivity to conventional integrating X-ray detectors, and has been successfully demonstrated to detect small fragments of plastic in chocolate bars.

Introduction

The food industry makes every effort to keep unwanted material our of food products. Monitoring normal products and detecting anomalies is routine practice, using X-rays to detect metal and other high-density contaminants. However, low-density contaminants are difficult to pick up — such as plastic fragments in chocolate bars, which might arise if, for example, the mould becomes damaged or a sorting paddle breaks during processing.

Even though chocolate bars from a given processing line have the advantage of being very repeatable in shape and material density in three dimensions, there is little or no contrast between plastic and chocolate to make a difference to the X-ray absorption image, either in intensity or shape of features.

In a single exposure at a single X-ray source kV, IBEX technology delivers energy-dependent information to conventional, integrating X-ray detectors, such as silicon flat panels or line scanners, thus adding *material* information distinct from material thickness information. This means that X-ray inspection need no longer rely on absorption contrast, but can make direct use of the difference between materials in the sample.

Multi-Absorption Plate (MAP) Technology

IBEX MAP (Multi-Absorption Plate) technology modulates the X-ray spectrum reaching the detector in a regular manner across its surface. In addition, sophisticated mathematical models are used to detect subtle contaminants in repeatable products such as chocolate bars or jars of baby food. IBEX technology is described in detail in our White Paper, available from the Resources page of our website.

Experiment

Two sets of experiments are presented: chunky chocolate bars, and bars containing wafers. In both cases, samples were purchased locally and contaminated in our lab by first heating a soldering iron, then letting it cool significantly, until it could melt chocolate locally without either burning the chocolate or causing too much crystallisation on further cooling. (Such damage or excessive crystallisation is visible in absorption contrast and IBEX materials contrast images). In some of these puddles, a piece of plastic was placed. Other puddles were left to cool without contamination, thus creating a slightly deformed region of chocolate locally.

The data were collected using an in-house, fixed cabinet X-ray system fitted with a low-power, micro-focus, tungsten-target X-ray source running at 80 kV, 3.9 W. The detector was a Dexela 1512 CMOS flat-panel detector equipped with an IBEX Multi-Absorption Plate (MAP).

Since the equipment used was static and manually operated, the samples were kept in a refrigerator near the X-ray equipment, in order to minimise the chances of deformation due to handling. Wrappers were removed in order to maximise reproducibility of sample positioning against a right-angle jig.

Chunky Chocolate Bars

In the chunky chocolate bars, the molten chocolate puddles were made in the flat faces of the chunks. In some of these puddles, a piece of plastic cut from a dense polystyrene sorting paddle was placed. The pieces were ~2-3 mm across and ~2 mm thick. Other puddles were left to cool without contamination, thus creating a slightly deformed region of chocolate locally.

The samples were positioned in order to zoom in on two middle chunks of the chocolate bars, to improve spatial resolution over the small pieces of contaminant.

First, 20 "clean" chocolate bars (uncontaminated and undeformed) were imaged. The images were analysed in order to train the system in the materials signature of chocolate, and to build the statistical model of a "normal" clean bar and the typical variation within "normal" over a number of clean bars.

Next, a set of ten test bars was measured. Three of these bars had been contaminated. The materials signals of these bars were compared by the software to the model of a "normal" chocolate bar previously created. Where the algorithm identified suspect areas in the test bar, these were subjected to a second, more local test. At this point, the algorithm automatically decided whether the suspect area contained a plastic contaminant, or was a disturbed area of chocolate (e.g. a puddle, deformation caused by handling or an unusual bubble). In the output image, a region containing a contaminant was coloured orange (even though the contaminant might not fill the suspect region) and regions identified as bubbles or disturbed or deformed chocolate were coloured green.

A second training set of 20 bars was measured, followed by a further test set of eight bars. Four of these were contaminated with plastic pieces. The two test sets are presented together in the results below. The first set is numbered Bars 1 to 10; the second, Bars 11 to 18.

Chocolate Wafer Bars

Pieces of polystyrene paddle material and/or polycarbonate pieces from a chocolate mould, typically ~3-5 mm across, were used to contaminate a number of chocolate wafer bars on their flat surfaces. Melted and re-solidified chocolate regions were also created in some samples.

As with the chunky chocolate bars, 20 clean wafer bars were first measured in order to build a mathematical model of a normal wafer bar. Forty test samples were then measured, of which eight were contaminated, although 11 of the 40 measurements (including one contaminated sample) had to be excluded from the analysis due to sample alignment issues.

The presence of the wafers, which have a cross-hatched pattern and are less dense than chocolate, increases the complexity of the model. In addition, the X-ray absorption of polycarbonate is even more similar to that of chocolate than is the absorption of polystyrene, meaning that the analysis needs to be even more sensitive.

Results and Discussion

Chunky Chocolate Bars

IBEX materials technology and mathematical analysis successfully identified the contaminated chunky chocolate bars, with no false positives. Some example results are shown in Figures 1 to 3, below.

The materials signal and difference from "normal" of deformed chocolate regions behave differently from the materials signal of the plastic contaminants, enabling the two cases to be distinguished. Where bubbles appear systematically in the same locations in the chocolate bars used for training, bubbles in these locations in the test bars are not identified as suspect, since they are within the model of "normal". However, bubbles in other locations may be highlighted for further investigation, but then classed as not being plastic contamination.

Figure 1 shows the X-ray absorption contrast and IBEX materials contrast images for Bar 14. The absorption contrast image is obtained by stripping the shadow of the MAP from the data. There is only weak absorption contrast relating to the deliberate contamination, and the same contrast levels are found in other, good regions of the sample. IBEX materials contrast clearly identifies the contaminated regions and also highlights some unusual bubbles near the vertices of one of the chocolate chunks.

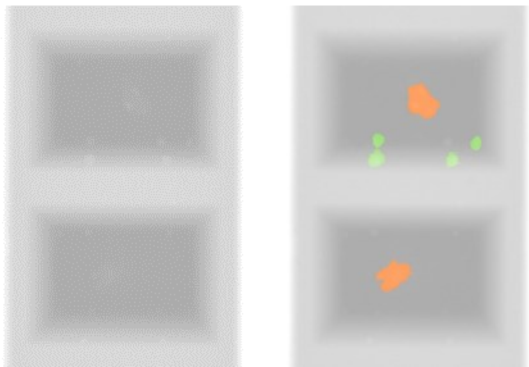

Figure 1: Left: X-ray absorption contrast image of Bar 14. Right: IBEX materials classification overlay image. Plastic contaminated regions are highlighted in orange; unusual bubbles or deformed areas of chocolate are highlighted in green.

Data for Bar 16 are shown in Figure 2. In this case, the eye easily spots an anomaly in the upper chunk of the chocolate bar in the absorption contrast image, while the disturbance in the lower chunk is barely visible. However, IBEX materials technology reveals that it is the region with lower absorption contrast which contains the contaminant, while the suspect region in the upper chunk is deformed chocolate (the result of local melting

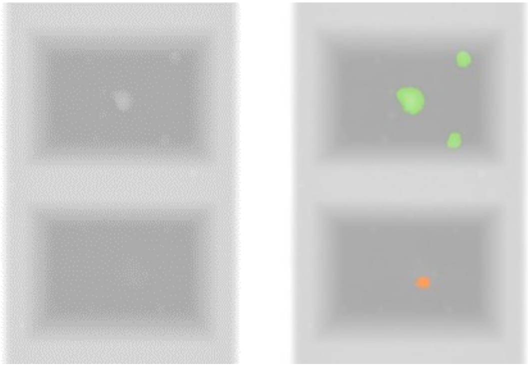

Figure 2: Bar 16. Left: absorption contrast image, obtained by stripping out the shadow of the MAP from the data. Right: IBEX materials classification overlay: deformed chocolate and bubbles are highlighted in green; contaminated regions in orange. The region identified as containing plastic is barely detectable in the absorption contrast image.

with the cooled soldering-iron). In both cases, the grey levels of the anomalous regions in the absorption contrast image are similar to those found in other, normal regions of the chocolate bar. Materials discrimination is necessary in order to identify the contaminated region correctly.

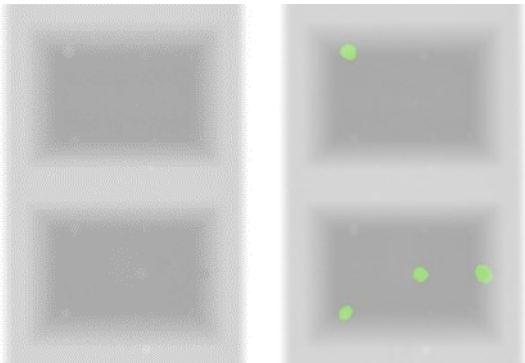

Figure 3: Bar 2. A few bubbles are apparently visible in the X-ray absorption contrast image (left). These are not all highlighted in the materials image (right) since some of them are regular features in the clean bars used to train the model of a normal bar. The unusual bubbles are highlighted and correctly identified as being deformed chocolate and not plastic contamination (right).

Absorption information is insufficient or even misleading.

Several suspect regions were highlighted in Bar 2 (Figure 3) but all were found not to be contaminated. Some bubbles apparently seen in the absorption contrast image have not been highlighted as suspect. This is because bubbles in these locations feature in many of the clean chocolate bars in the training set, and are thus within the model of a normal bar.

The analysis algorithms give quantitative measures of the degree of anomaly of a region in the chocolate bar identified as suspect, based on the difference in the material signal compared to the model of a "normal chocolate bar". The values for small deformations of chocolate are scattered around the level of the normal bars used to train the system. Highly deformed chocolate gives a large value to one side of this, while plastic contamination gives large values to the other side of the "normal" level (Figure 4). This quantification of anomaly allows a threshold to be set,

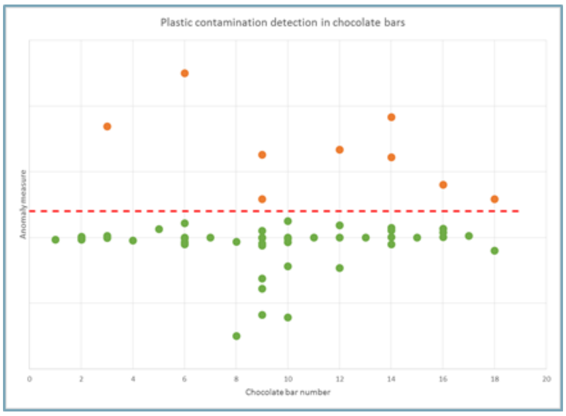

Figure 4: Quantitative scoring of the degree of anomaly compared to normal chocolate. Above the threshold (red dashed line), the anomaly measure indicates plastic contamination. Below the threshold is normal or deformed chocolate.

permitting a pass/fail decision for each bar. It may also be possible to set another threshold, to reject bars with excessive deformation of chocolate.

Chocolate Wafer Bars

Figure 5 shows example images the anomaly measures of four sections of chocolate wafer bars (full width across four wafer fingers; part length). “Normal” is shown in black in this case, while anomalies are coloured grey to white, according to the anomaly measure. Both polystyrene and

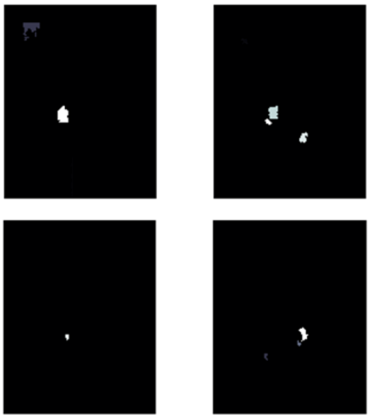

Figure 5: Top left: a polystyrene contaminant highlighted; top right: one polystyrene and one polycarbonate contaminant; bottom left: a polycarbonate contaminant; bottom right: a polystyrene contaminant.

polycarbonate contaminants have been successfully identified.

In the same way as for the chunky chocolate bars, the quantitative anomaly measure allows a pass/fail threshold to be set (Figure 6).

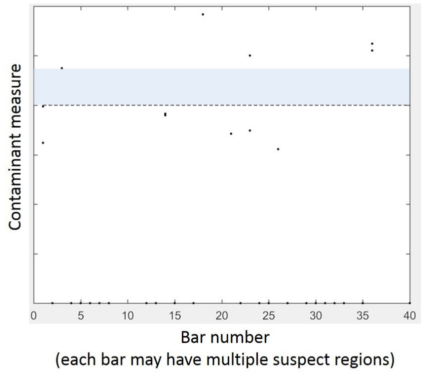

Figure 6: A plot of anomaly (or contaminant) measure, with a threshold set (dotted line). There is a clear distance (pale blue panel) between wafer bars containing contaminants (above) and clean bars (below the threshold).

Conclusions

IBEX materials contrast technology has positively detected dense polystyrene fragments from a sorting paddle in bars of chocolate, distinguishing this contamination from bubbles and regions of deformation in the chocolate bar; and detected polycarbonate and dense polystyrene contaminants in chocolate wafer bars.

The approach relies on recovering energy-dependent X-ray transmission information thanks to the insertion of the IBEX Multi-Absorption Plate (MAP) before the conventional detector in a single-kVp X-ray imaging system, obtaining the data in a single exposure.

The method is compatible with implementation on a continuous-process production line, where the quantitative measure of anomalies is ideally suited to Pass/Fail thresholding. The accuracy of the pass/fail decisions improves with use as the algorithm refines its model of “normal” with each clean bar measured.

Avenues for further work could include confirming the application for other types of plastic contaminants and extending the modelling to cover other shapes and compositions of chocolate bars. Bars containing wafers or biscuits or with non-moulded finishes (such as the ripples on a chocolate-coated biscuit) add levels of complexity to the analysis.

See more IBEX white papers and other resources by visiting our website, www.ibexinnovations.co.uk.

About IBEX

IBEX Innovations Limited was created in 2010 to develop and commercialise an innovative X-ray detector technology.

IBEX is based in modern facilities on the NETPark Science Park in the North-East of England, where it employs a team of highly skilled scientists, engineers and business professionals.

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Contact

IBEX Innovations Ltd.
Discovery 2
NETPark
William Armstrong Way
Sedgefield
TS21 3FH
UK

T: +44 (0)1740 625 526

W: www.ibexinnovations.co.uk