Detecting plastic contamination in chocolate

Ben Lopez, Adam Ratcliffe, Adam Hirst, Jordan Hall and Tamzin Lafford

IBEX Innovations Ltd., Discovery 2, NETPark, William Armstrong Way, Sedgefield, TS21 3FH, U. K.

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 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 out 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 often difficult to pick up – such as plastic fragments in chocolate bars, which might arise if the mould becomes damaged or a sorting paddle breaks during processing.

Even though chocolate bars from a given production line have the advantage of being very repeatable in shape 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 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.

IBEX technology

The absorption of X-rays by a material depends on the material type, its thickness, and the energy of the X-rays (Eq. 1):

$$I(E) = I_0(\mathrm{E})\exp(-\mu(E)t) \qquad \text{Eq. 1}$$

where $I(E)$ is the intensity incident on the detector, as a function of energy; $I_0(E)$ is the incident intensity, as function of energy; $\mu(E)$ is the linear attenuation coefficient of the material as a function of energy, and t is the material thickness.

The X-ray imaging detectors most widely used are based on silicon with a scintillator in front. These are rapid, relatively inexpensive, reliable and available in large areas. They measure an integrated signal in each pixel – spectral information is lost. There is therefore no direct way to determine both material and thickness from the signals obtained. While spectroscopic detectors are available, they are generally slower than silicon detectors, more expensive and are not usually available in large areas.

IBEX overcomes the limitations by placing a patented Multi-Absorption Plate (MAP) in front of a standard X-ray imaging detector, which could be a flat-panel or a line scanner or other configuration. The MAP is a 3D periodic structure which modulates the X-ray spectrum in a predictable manner over a few pixels, repeating the pattern across the area of the detector. Materials information is extracted from the modulated image, enabling generation of an image based on differences between materials, rather than on X-ray absorption contrast. Once the material is identified, thickness information is then also available.

The results can be presented in a variety of ways, depending on the requirements of the application. A high resolution, conventional absorption contrast image is returned as part of the process.

Figure 1 schematically shows a conventional X-ray imaging system: the source delivers a spectrum of energies which are attenuated by the sample according to the material thicknesses and densities in the beam path. The resulting absorption contrast image is collected using a flat-panel detector or a line scanner. In this example, there are three bone fragments in the mass of chopped chicken, but they cannot be identified in the range of grey levels in the absorption contrast image.

Introduction of the IBEX MAP (Figure 2) allows a materials image to be constructed. Having identified the contaminants, the information may be presented in various ways, such as the materials contrast and contaminant overlay images shown.

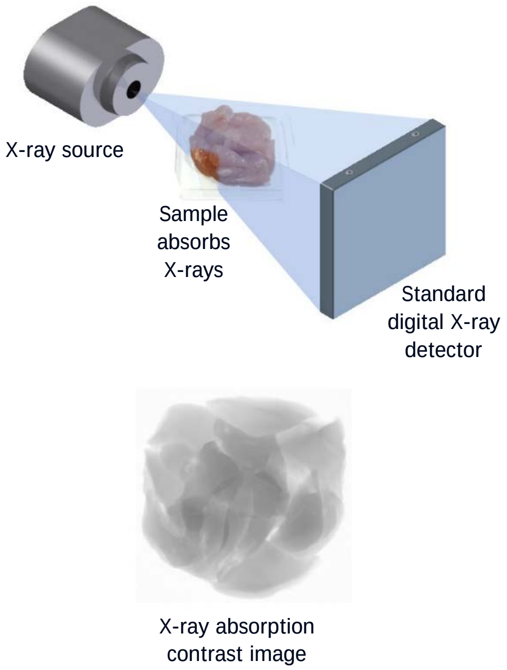

Figure 1: Conventional X-ray absorption contrast imaging. The X-ray source delivers a spectrum of energies. The X-rays are attenuated by the sample according to the materials and their thicknesses in the path of the beam, resulting in an absorption contrast image.

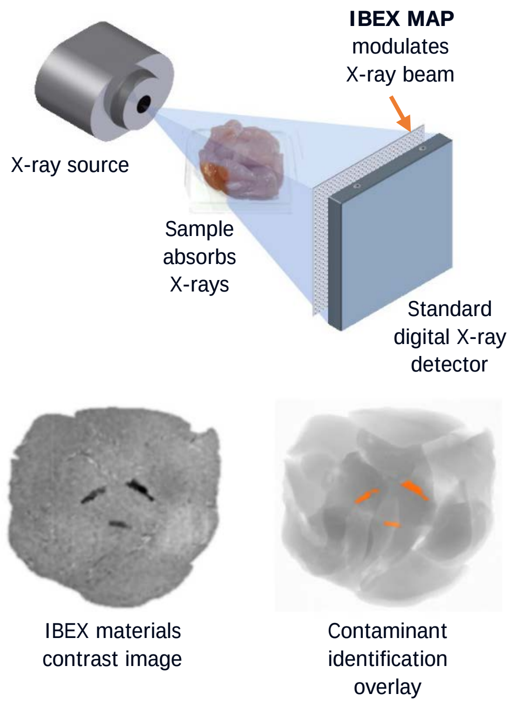

Figure 2: An IBEX MAP-enabled system. The MAP modulates the image in a predictable manner, allowing recovery of energy-dependent information leading to construction of a materials contrast image, as seen above.

For detecting occasional contaminants in samples of otherwise repeatable product, such as a series of chocolate bars (the subject of this paper) a statistical model is built of "normal" product. The model is based on beliefs about the mathematical description of non-contaminated product (material, shape, etc.) and is automatically updated by incorporating information on clean samples and the normal, acceptable variations between them, as they are measured. Automated decision rules are employed to create an on-line algorithm capable of detecting contaminant fragments, since their material "signature" differs from that of normal chocolate.

Experiment

Chunky chocolate bars

A number of chocolate bars were purchased from the supermarket. Some were contaminated with pieces of dense polystyrene, cut from a sorting paddle. The pieces were ~2-3 mm across and ~2 mm thick. Contamination was done 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). The molten chocolate puddles were made in the flat faces of the chunks. In some of these puddles, a piece of plastic from the paddle 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 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). 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.

Since the equipment used was static and manually operated, the samples were kept in a fridge 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.

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, or deformation caused by handling). 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.

Results and Discussion

Chunky chocolate bars, substitutional plastic contaminants

IBEX materials technology and mathematical analysis successfully identified the contaminated bars, with no false positives. Some example results are shown in Figure 3 to Figure 5, below.

The materials signal of deformed chocolate behaves 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 3 shows the X-ray absorption contrast and IBEX materials contrast images for Bar 14. There is only weak absorption contrast relating to the deliberate contamination. IBEX materials contrast clearly identifies the contaminated regions and also highlights some unusual bubbles near the vertices of one of the chocolate chunks.

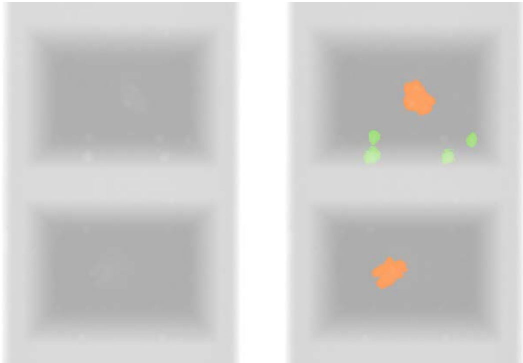

Figure 3: Left: X-ray absorption contrast image of Bar 14. Right: IBEX materials classification overlay image. Plastic contaminated regions are highlighted in orange; unusual bubbles or deformed areas of chocolate are highlighted in green.

Data for Bar 16 are shown in Figure 4. 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. IBEX materials technology reveals that it is the lower-contrast region which contains the contaminant, while the region in the upper chunk is deformed chocolate (the result of local melting 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. Absorption information is insufficient or even misleading.

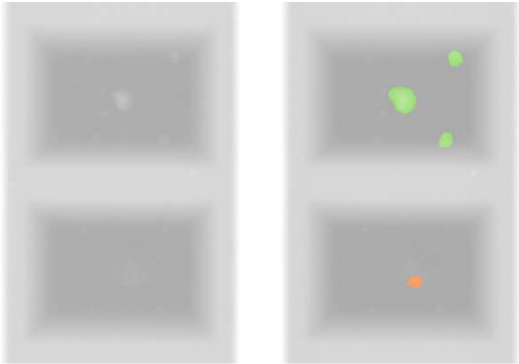

Figure 4: Bar 16. Left: absorption contrast image; right: IBEX materials classification overlay: deformed chocolate and bubbles highlighted green, plastic contaminated region highlighted in orange. The region identified as containing plastic is barely detectable in the absorption contrast image.

Several suspect regions were highlighted in Bar 2 (Figure 5) 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.

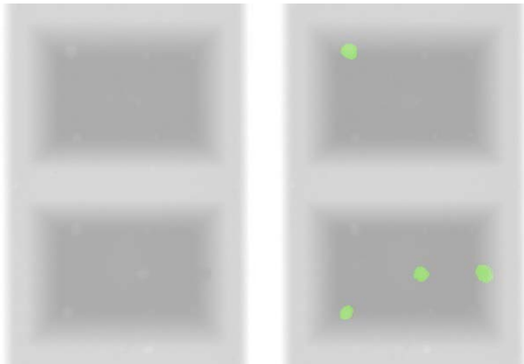

Figure 5: Bar 2. A few bubbles are apparently visible in the X-ray absorption contrast image (left). These are not all highlighted in the materials image (right) since some of them are regular features in the clean bars used to train the model of a normal bar. The unusual bubbles are highlighted and correctly identified as being deformed chocolate and not plastic contamination (right).

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 "normal chocolate bar" model. 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" line (Figure 6). This quantification of anomaly allows a threshold to be set, 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.

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. The approach relies on recovering energy-dependent X-ray transmission information thanks to the insertion of the IBEX Multi-Absorption Plate

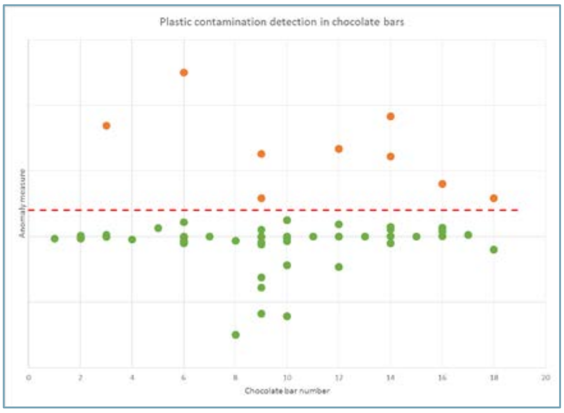

Figure 6: Quantitative scoring of the degree of anomaly compared to normal chocolate. Above the threshold (red dashed line), the anomaly measure indicates plastic contamination. Below the threshold is normal or deformed chocolate.

(MAP) before the conventional detector in a single-energy 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/polycarbonate contaminants and extending the modelling to cover other shapes and compositions of chocolate bars. Bars containing wafers or biscuits or with non-moulded finishes add levels of complexity to the analysis.

References

IBEX technology is protected by a number of patent applications worldwide. See www.ibexinnovations.co.uk for the latest information.

