Detecting glass particles in glass jars of baby food

Ben Lopez, Adam Hirst and Tamzin Lafford

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

Abstract

IBEX technology has been successfully demonstrated to detect glass beads down to 1 mm in diameter in glass jars of puréed baby food in a standard X-ray imaging system using a conventional X-ray detector. Such contaminants present little or no contrast in X-ray absorption, a technique widely used in food safety inspection, making them very difficult to detect by these means. By applying IBEX MAP technology to recover energy-dependent information from a standard X-ray detector with the X-ray source working at a single peak kV, images are generated based on contrast between the materials (rather than a combination of their thickness and density). Contaminant particles can then be highlighted by their material difference from normal product.

There are no inherent barriers to applying this technology at speeds compatible with food production lines.

Introduction

Food safety is obviously very important, and infants are at particular risk if their food is contaminated.

Glass jars running through a production line occasionally get chipped, potentially leaving small fragments of glass in the contents of the jar. These are a health hazard, particularly to a baby, and such fragments are not necessarily easy to spot visually on spooning out the contents, since glass is optically transparent, while the food is generally opaque. Identifying and rejecting contaminated or damaged jars of baby food before they leave the factory is a critical step in the quality assurance process.

X-ray inspection systems are used routinely in the food industry to monitor production quality. However, low-density contaminants such as glass and plastic in food are difficult to detect, since there is little or no X-ray absorption contrast between the contaminant and the food product. IBEX technology brings the contaminants to light by recovering energy-dependent information from conventional X-ray detectors in images collected at a single source kV setting. This leads to differentiation between materials directly, independent of their thicknesses or absorption contrast, since their X-ray attenuation characteristics are a function of energy.

The capability of IBEX technology to detect glass beads down to 1 mm in diameter in glass jars of puréed baby food in a single-energy X-ray imaging system has been demonstrated. There are no intrinsic obstacles to applying this technology on a production line.

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 via 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.

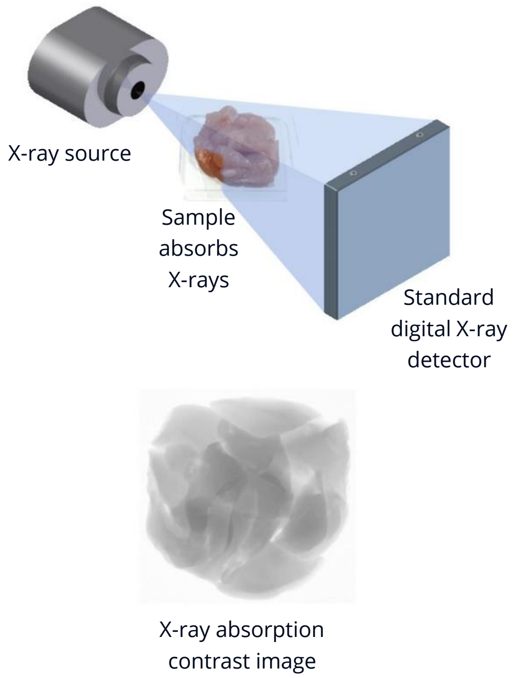

Figure 1: Conventional X-ray absorption contrast imaging. The X-ray source delivers a spectrum of energies. The X-rays are attenuated by the sample according to the materials and their thicknesses in the path of the beam, resulting in an absorption contrast image.

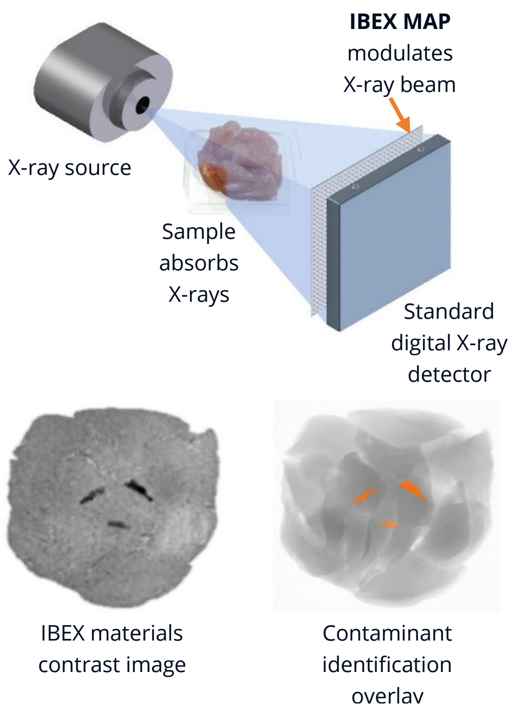

Figure 2: An IBEX MAP-enabled system. The MAP modulates the image in a predictable manner, allowing recovery of energy-dependent information leading to construction of a materials contrast image, as seen above.

For assessing a repeatable product such as a jar of baby food, a statistical model is built of "normal" product, using known clean examples. The model is based on beliefs about the mathematical description of non-contaminated product and is automatically updated by incorporating information on clean samples and the normal, acceptable variations between them, as further samples are measured. Automated decision rules are employed to create an algorithm capable of detecting contaminant fragments, since their material "signature" differs from that of baby food. The model includes descriptions of the materials (the baby food and its container) as well as the shapes associated with the product.

The MAP does not add overheads to image acquisition, and data processing can be done in real time, so there are no fundamental barriers to implementing this technology in a production environment.

Experiment

Samples were measured using an in-house, fixed cabinet X-ray system fitted with a conventional, low-power, tungsten-target X-ray source running at 160 kV, 0.5 mA (80 W). Given this low power compared to typical inspection systems, the total integration time per image was 7.5 s in order to give high signal-to-noise within this test. (This time would be much reduced on a production tool). The detector was a Rayence 1417 WGA CMOS flat-panel detector equipped with an IBEX Multi-Absorption Plate (MAP). Jars were mounted by hand against an alignment jig.

First, 20 glass jars of puréed baby food (all the same variety) were measured and the images analysed in order to build the mathematical model of normal product, including the acceptable variation within "normal", and to train the analysis system in the materials "signatures" of the baby food and jar. Sample images were corrected for flat-field and dark-field prior to IBEX materials analysis.

Five additional jars were deliberately contaminated with glass beads 1 mm, 2 mm and 3 mm in diameter placed in the bulk of the baby food. These were then measured along with a further 14 uncontaminated jars, in random order, in the test run.

Figure 3: Left: one of the jars of puréed baby food used in the trial. Right: glass beads used for the contamination.

Results and Discussion

Besides low/no contrast between the glass bead contaminants and the baby food in glass jars, a particular challenge in this case is that the shape of the sample varies slightly between samples. The shape of the meniscus of the contents is not constant; neither are the details of the shape of the glass jar and its local thickness. These variations must be recognised within the model of "normal", whilst retaining sensitivity to deviations from normal caused by contaminants.

Using IBEX materials contrast technology, the glass contaminants stand out well against the puréed baby food, despite some local variations in jar thickness. All five contaminated samples were correctly identified, with a clear, quantitative distinction between contaminated and uncontaminated jars. An example is shown in Figure 4 and Figure 5. Figure 4 shows the absorption contrast image (the IBEX image with the effect of the MAP stripped out). It is hard to see the glass bead contaminants in this image. Figure 5 shows the contaminants identified using IBEX materials technology, highlighted in orange overlaid on the absorption contrast image.

Figure 4: Absorption contrast image of a contaminated jar of baby food. The glass bead contaminants are barely visible. The pale rectangle in the bottom left of the image comes from the alignment jig used in this test where the samples were positioned manually.

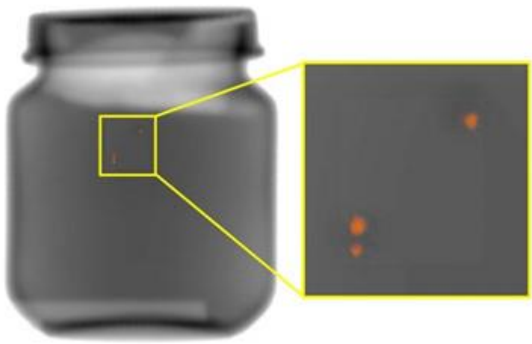

Figure 5: IBEX materials technology detects the contaminants. In the image above, they are shown in orange.

In this demonstration of capability, there were no false positives and no false negatives. Images of all 19 test jars, with contaminants highlighted, are shown in Figure 6.

Figure 6: Absorption contrast images of all 19 jars in the test set. The glass contaminants were successfully detected in the five contaminated jars. These are framed in yellow, with the contaminants themselves highlighted in orange.

Contaminant detection based on IBEX materials technology delivers a measure of "contaminant significance" for each sample. The values for uncontaminated samples are scattered around some mean value, while values for contaminated jars are markedly different (Figure 7). This allows a threshold to be set to discriminate between contaminated and uncontaminated jars, as a pass/fail criterion in a production environment.

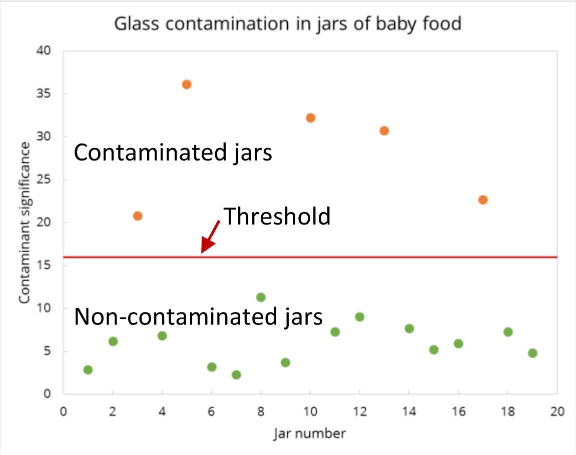

Figure 7: Quantitative measures of "contaminant significance" enable thresholding in a production QA environment. This test showed clear differences in this measure between contaminated and non-contaminated samples.

Conclusions

In a demonstration of capability, IBEX materials contrast technology successfully identified five jars of baby food deliberately contaminated with glass beads from a test set of a total of 19 jars. The difference in the quantitative measure of "contaminant significance" between clean and contaminated jars opens the possibility of pass/fail thresholding in a production environment. There are no inherent barriers to this technology being applied at production-line speeds and it may be used with flat-panel or line detectors.

Acknowledgments

Thanks to Jordan Hall for technical support in data collection, and to Adam Ratcliffe for help with data analysis.

References

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

