CASE STORY:

Using X-ray technology for on-line Process Control

INTRODUCTION

X-ray systems are widely applied for numerous applications relative to **foreign body contamination** of products. Lately, the technology has been developed towards a higher resolution and a higher contrast, while retaining a high speed of scanning.
There is limited awareness on the complex on-line measurement and quantification tasks that can be solved cost-effectively using advanced X-ray technology, within a large range of application sectors.

PROCESS CONTROL USING X-RAYS

Unlike vision systems, which are very widely used for process control, X-ray imaging can provide information on the **internal geometry of the inspected object**. **Internal dimensions and tolerances** may thus be ascertained using **high resolution, high contrast, X-ray systems,** and deviations can be handled instantaneously. Such **X-ray inspection and sorting** is relevant for a vast number of production cases, e.g. **X-ray inspection of bakery products (bread, biscuits, cakes)**, of **cheese structure** (e.g. **hole and cavity development, voids, density variations**), of **fruit ripeness development**, of **lobster and crab grading,** of **seed sprout capability inspection**, and **X-ray systems for chocolate and confectionary inspection**, as examples.

InnospeXion provides solutions based on various X-ray technologies with a detection level down to the micro-meter range, and with the highest sensitivity in the market (i.e., ability to discriminate between different compositions and their quantitative distribution, inside the product).

When the X-ray system detects a non-conformity, the automatic image analysis processing will provide the result to the system PLC. The PLC will in turn provide this signal for the production line control system, as well as for a reject/sorting station. This communication takes tens of milliseconds, and secures a real-time processing. Read more about our **X-ray technology here.**

For the above mention applications, quantification examples provided by **high resolution, high contrast X-ray systems** includes:

- To ascertain that the structure, overall homogeneity, size and weight of dough for **biscuits and cakes** conforms to the specification;
- To ascertain that the meat content of live shellfish (**lobster and crab grading**, e.g.) conforms to the market expectations;
- To ascertain that the **ripeness of fruit** is adequate for sale;
- To ascertain that the **sprout capability of seeds** makes them valuable for usage;
- To validate the **maturity development of cheese** to identify the optimum time for its release for sale;
- To secure that the **sealing and packaging process of products is in conformity** with the specifications;
- To ascertain that the conformity of the production, e.g. in case of **chocolate and confectionary**, meets the requirements for their **correct packaging and quality**.

BIG DATA AND THEIR PROCESSING

The X-ray image acquired of each individual product provides a large amount of data. The quantification and derivation of relevant measures can be applied for the continuous production control and monitoring.

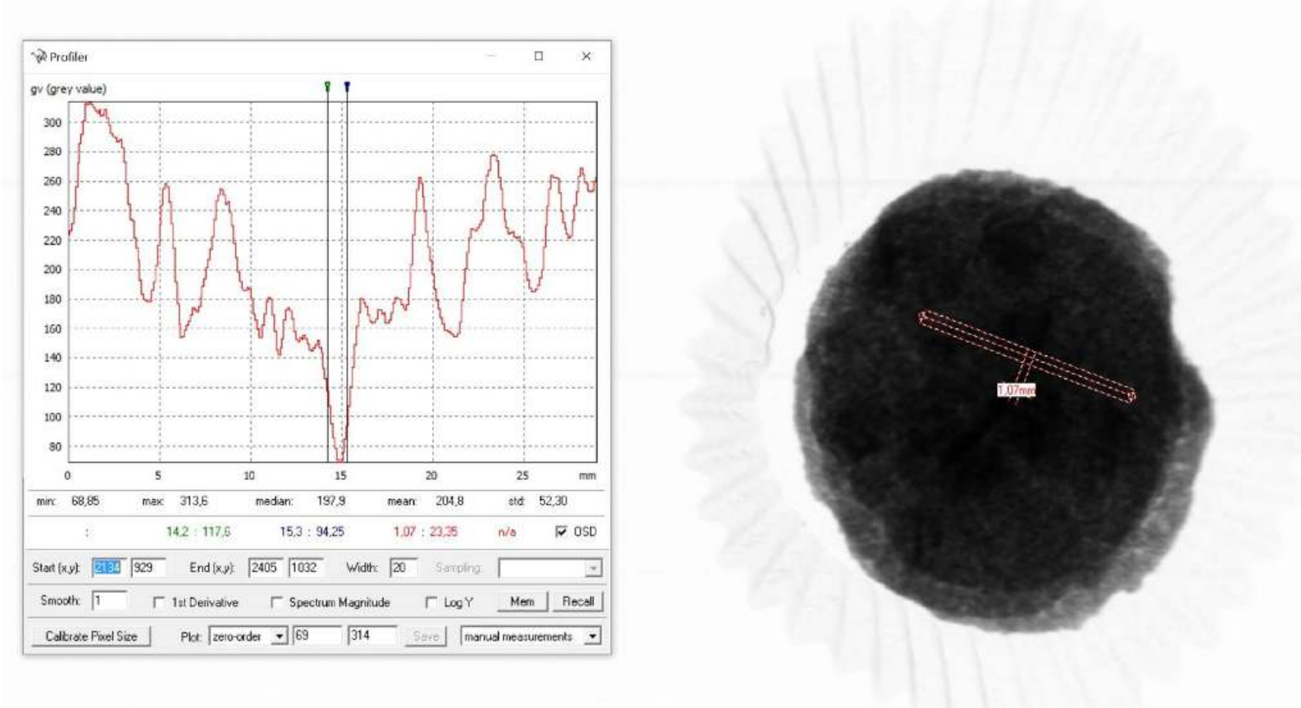

Fig. 1. Low-energy **X-ray scanning** image of a **bakery product** (**cake or biscuit**) in a paper cup. The profile line near to the center (curve at left) shows a central dip, caused by a small **PVC contaminant**. The profile also shows other less marked dips, which correlates to large (mm-sized) sugar crystals on top of the **cake or biscuit**. The profile grey level values can also be correlated to the total thickness, or mass variation, across the **cake or biscuit**. This can be used for sizing estimation of the unbaked cake, and process control that the baked cakes satisfies the dimensional tolerances given by the **cake or biscuit** packaging system.

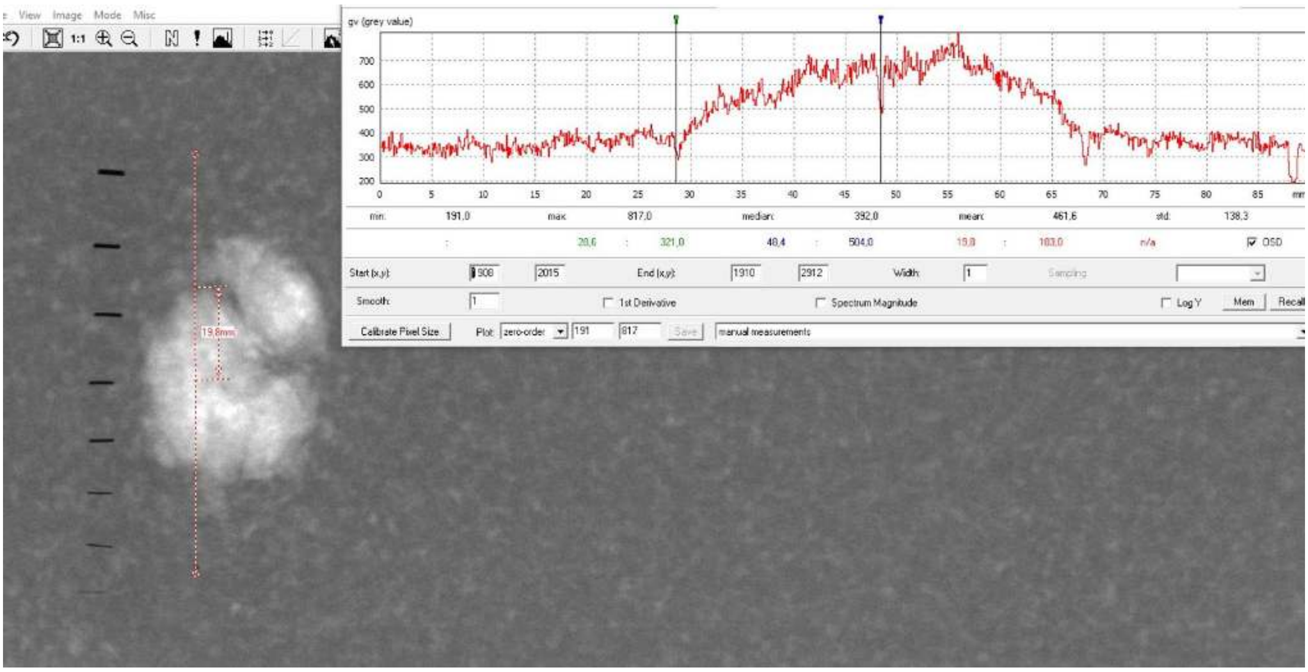

Fig. 2. X-ray image of a tilsiter **cheese**, showing anomaly large **void or cavity. Development** of such **voids** or **cavity** can be monitored by the **X-ray system** during **cheese maturation** and facilitate the release for sale.

An **X-ray system** image displays the attenuation of the X-rays having passed the scanned item. The attenuation depends on the composition and thickness (or density). Therefore, the grey level value of a pixel can be correlated to details in the item that are relevant to control, or monitor. This may e.g. concern the distribution of various compounds in a mixture, to ascertain the homogeneity of a product. It may also be used to quantify the **structure and the dimensions of holes, voids or cavities in cheese**, in order to to provide a measure of the **maturity development of the cheese**. Examples on the above is reflected by Figs. 1 and 2.

In general, the X-ray image information content is large and it can enable a close monitoring of the product tolerances being satisfied, and provide an alarm at the moment one or more parameters reach the boundary tolerance limits. This enables the on-time reaction and correction of a process, avoiding faulty production.

The example below (Fig. 3) shows an **X-ray system** applied for the **complete product monitoring** including the **packaging and the contents**. (LINK TO SEAL INSPECTION PAGE). This is based on measuring the grey level distribution within the X-ray image of each scanned product, as well as a close monitoring of the (projected) content volume. The statistical data of the latter enables a direct comparison of the production, sample to sample, batch to batch, etc.

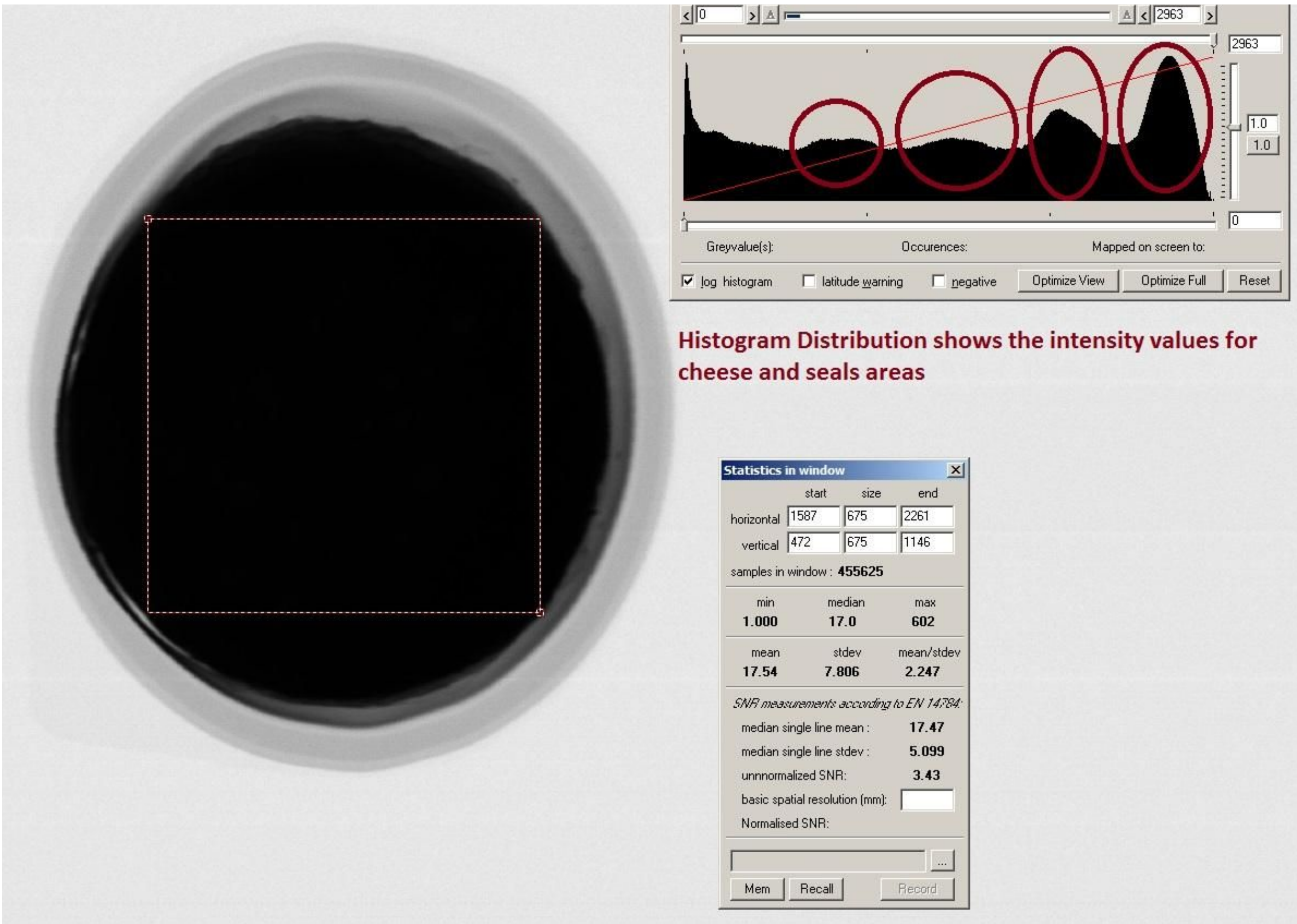

Fig. 3. Example on fast conformity assessment for **packaging and contents inspection**. This is based on histogram analysis for each X-ray scanned item. The content analysis may also be based on statistical analysis of the grey level distribution. This correlates to the homogeneity of the content and deviations indicates the presence of foreign objects and other conformity irregularities.

THE USEFULNESS OF X-RAY BASED PROCESS CONTROL

Large production sites with very long production lines are vulnerable to unscheduled stops due to irregularities which may often only be detected in the packaging area. This is e.g. why **X-ray inspection of chocolate and confectionary** is important. The very extensive and wide production lines may carry many thousands of products, and the ability to quickly identify an important irregularity in the mould, forming or shaping equipment may have a significant value (fig. 4).

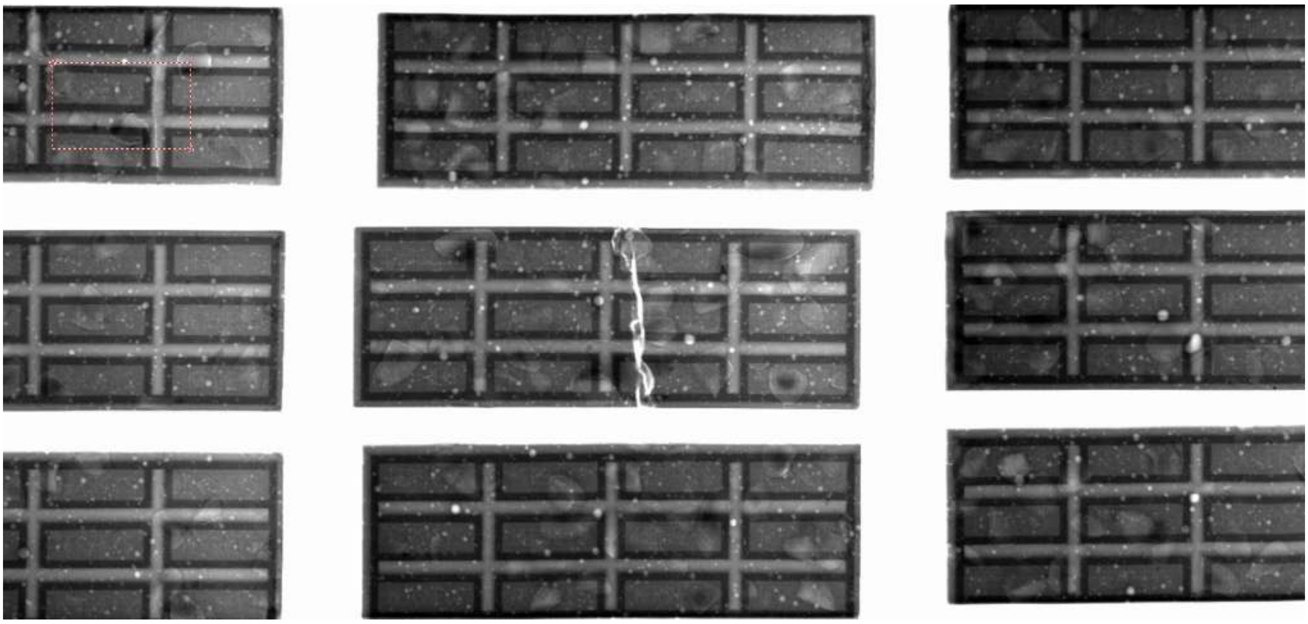

Fig. 4. **Low-energy X-ray system image of chocolate** bars (200 g) with hazelnuts. Note that the image clearly portrays the details of the bars, as well as the internal structure (voids, distribution of nuts), and defects (e.g. cracked chocolate bar in the middle).

Fig. 5 displays a typical situation upon testing of the trigger timing settings on **X-ray inspection** of a row of **chocolates.** The challenge is the width of the conveyor section and the correct triggering across the 38 rows to enable correct reject upon **X-ray based non-conformity detection**.

Fig. 5. Chocolate bar alignment prior to reject tests with 38 chocolate lanes across a 1600 mm conveyor width of a **chocolate X-ray inspection system**.

PROCESS CONTROL FOR FRUIT RIPENESS ASSESSMENT

Fruit and vegetables are vulnerable to a fast degradation, and timely assessment of the **fruit ripeness** stage and the timing of bringing the product to market is therefore important. **Low-energy X-rays** enables the quantitative assessment of the **ripeness stage or ripeness condition** of many fruits and vegetables. This is due to the internal structure change with the ripe condition. For example, avocados are difficult to assess based on their external presentation. Some are used for high end meals, such as sushi. It is important that the quality of a batch matches the user expectations. X-ray inspection may secure that the fruit is used when it is best, and eliminates costs of handling fruit that is worthless. Figs. 6 and 7 shows examples of **X-ray inspection of overripe avocado** and avocado in its best condition, relatively.

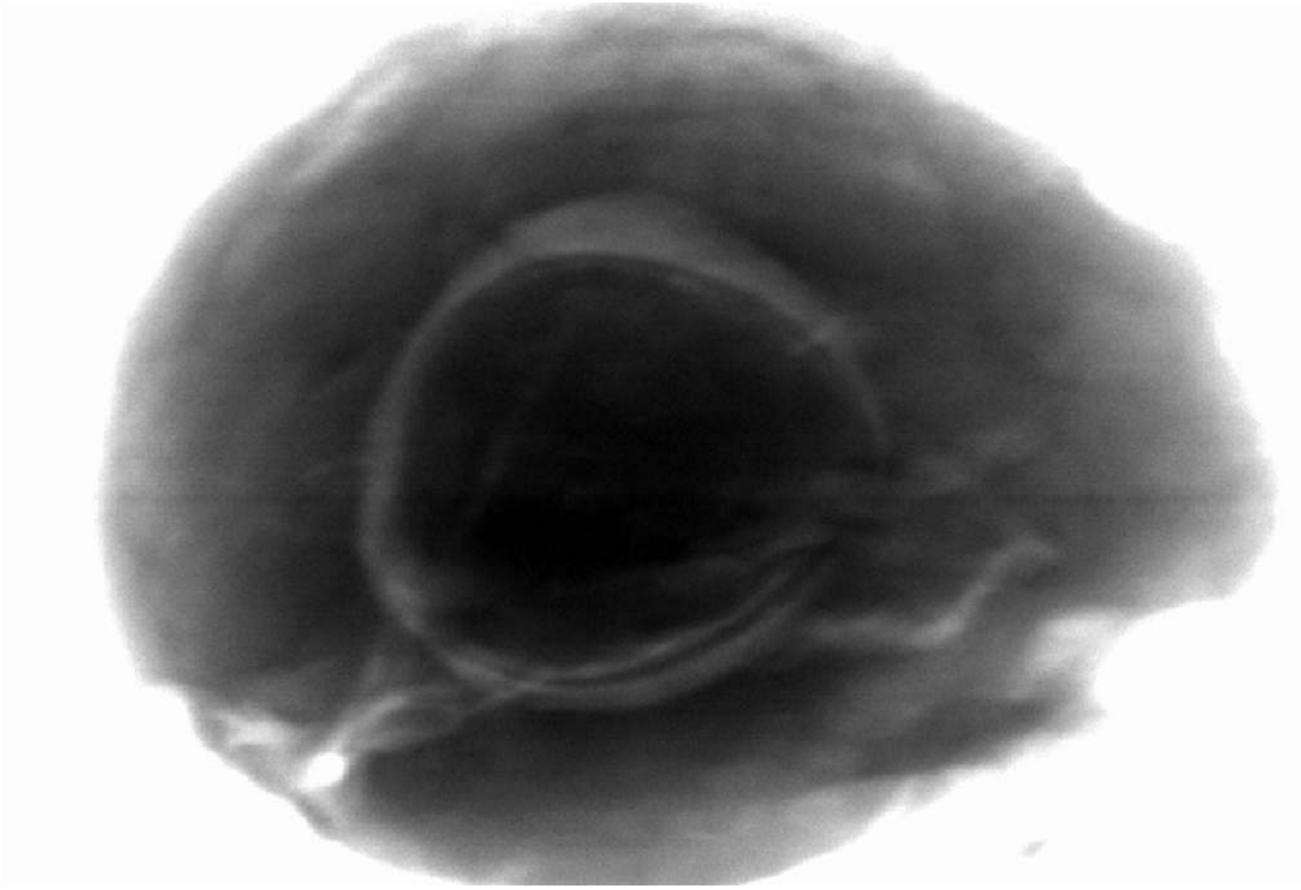

Fig. 6. **X-ray inspection image of over ripe avocado fruit**. The structure is fragmented and cracked, and a cavity is distinct at the core.

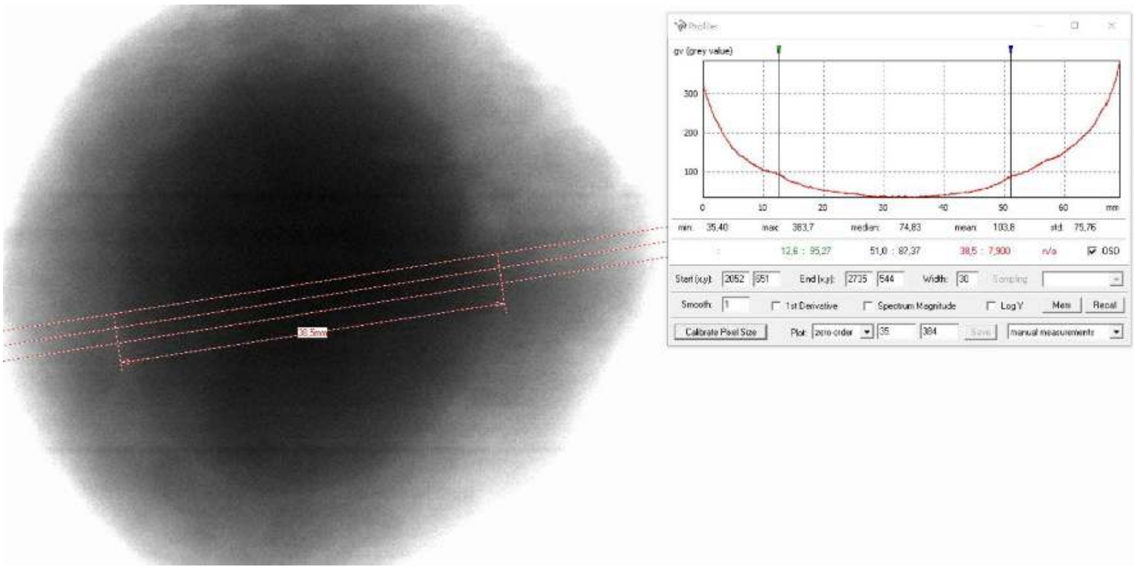

Fig. 7. **Low-energy X-ray inspection image of ripe avocado**. The structure is slightly mottled, and there is no void between the core and the fruit flesh. The density profile across the fruit at the right is even and regular without discontinuities, except the edges of the core itself (indicated). The density profile curve reflects the difference in total thickness as well as the compositional change by the core region.

PROCESS CONTROL: SORTING

Many modern processes rely on a **quality sorting of raw material**. **X-ray inspection** is in many cases ideal for such task. The low-energy technology brings many additional applications, thanks to the high contrast and the high resolution. Therefore, **X-ray based quality sorting** of very different items may be cost effective, e.g. **pearls**, raw materials for food, **seeds** for crops or trees, and many more. Fig. 8 displays an example of **X-ray inspection of seeds** for sugar roes. Here the farmland and time that may be wasted on poor seeds is significant, and a sorting may eliminate the use of resources on **seeds without the sprout capability**.

Many products gain further value if their quality grade can be quantified. This is e.g. the case with live lobsters and other crustaceans. A key quality factor is the meat content, which may vary substantially, and a live lobster may end up being seen as half empty relative to its shell size. **Lobster quality grading based on X-rays** involves therefore the assessment of the meat content. InnospeXion has developed a technology based on high sensitivity, high resolution imaging of live lobsters. By selecting proper parameters, a correlation from the X-ray image to actual meat content is possible (fig. 9).

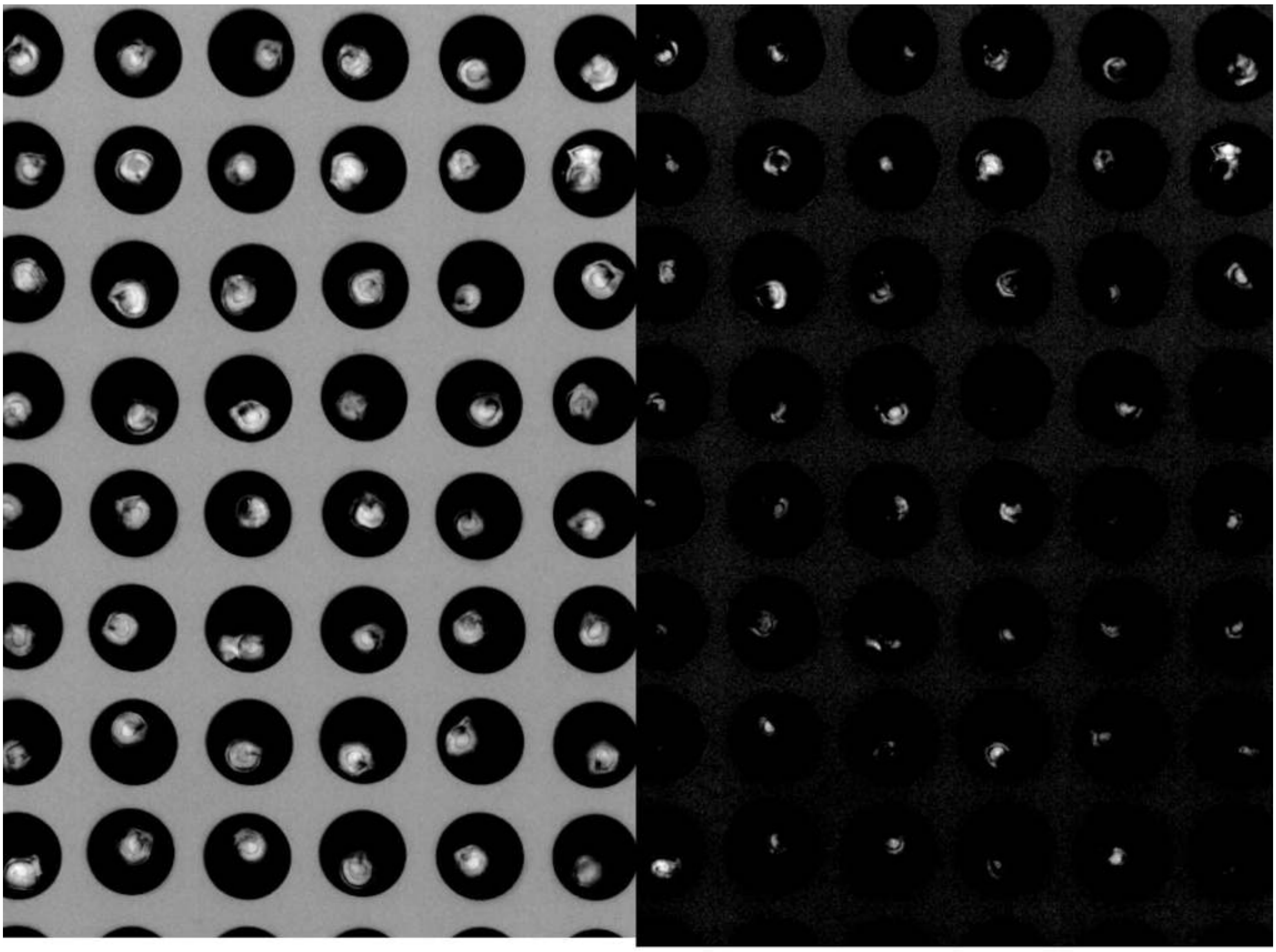

Fig. 8. Example on the use of low energy **X-ray inspection for seed sprout quality control**. The left part of the figure displays the **X-ray image of seeds**, individually placed in a tray. Some seeds are markedly lighter than others. This observation correlates to less material in the seed, and therefore reduced sprout capability. The right part of the figure shows the same image, but with a threshold to display only how much of the seed volume that are missing sprout building material. The larger the white/light spot, the less material, and the smaller ability to sprout. As can be seen, 6 to 8 out of 48 seeds are vulnerable to a poor sprout ability, therefore causing significant losses upon farming.

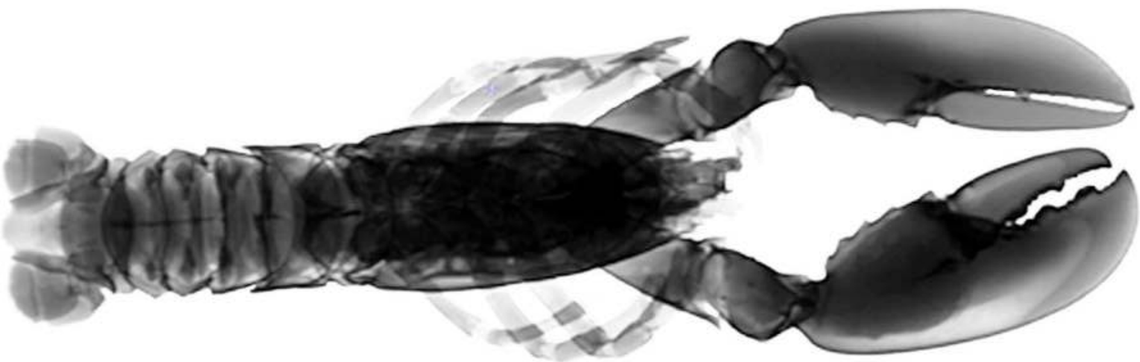

Fig. 9. High sensitivity, high resolution **X-ray image of live lobster for quality grading**. The meat content can be determined by combining several image parameters. It may in this case readily be seen that part of the claws is free of meat.

THE COST-EFFICIENCY OF X-RAYS FOR PROCESS CONTROL

X-ray systems placed on the production floor will today acquire a very substantial amount of information which relates to the products passed through the system.
Unfortunately, X-ray systems are mainly used for **detection of foreign objects of various sorts**, and typically used in the food sector where retailers impose a demand for inspection, owing to consumer safety and the costs of recalls. Traditionally, there has been very little interest in using information pertaining to the products, and the **X-ray systems** have not had significance for the **process control**, only for (final product) quality control.

The novelty is that the significant improvement in contrast and resolution has opened for new applications for X-ray systems. The special InnospeXion X-ray systems have thus proven their capability integrated to the production line, where non-conformities are detected, before they end up as a defect. In some applications, the ability to make a quantitative quality assessment has implied a better use of the raw materials, leading to a more rational manufacturing.

These benefits of new technology is that the X-ray technology no longer can be regarded as a final “go/no go” inspection tool, which only can be cost-wise appreciated if the rejected items can be connected with a price. The commercial gain on using the technology for control rather than discard is substantial. Deviations can be corrected for, before they end up as defects. This leads to savings, higher product value, less scrap, better use of resources, and less downtime.