XSpectra®: an Advanced Real-Time Food Contaminants Detector

B. Garavelli[1], P. Pozzi[1], D. Macera[1], L. Zanotti[1], A. Mencarelli[1], G. Bubba[1], P. Bertoni[1], M. Sammartini[2], M. Bettelli[3], G. Bertuccio[2], G. Ghiringhelli[2], A. Zappettini[3]

[1]Xnext s.r.l., Via Adelaide Bono Cairoli 30, 20127 Milano, Italy

[2]Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy

[3]IMEM-CNR, Parco Area delle Scienze 37/A, 43124 Parma, Italy

***Abstract*— An innovative X-ray inspection technology, named XSpectra®, has been developed with the aim to improve the current state of art in the field of real-time detection of contaminants in food products on production lines. The technology architecture is based on modules equipped with a 128 pixels CdTe array detector each read-out by full-custom Front-End ASICs. A full-custom Multi-Channel-Analyzer reconstructs the radiation spectrum, which is then processed by advanced Neural Network algorithms performing both image reconstruction and foreign bodies detection. The experimental characterization of XSpectra® has demonstrated the sensitivity of the fully operating system to photon energies down to about 10 keV at events rates up to several millions of photons per second. A line-width of 8.5 keV FWHM has been measured, at room temperature, on the 60 keV photo-peak of a synchrotron radiation in low-rate conditions. A spectral non-linearity error within ±0.5% has been obtained within the energy range 25 keV — 100 keV. The effective capability of XSpectra® to detect currently undetectable low-density contaminants inside real food products has also been proved.**

***Index Terms*— Non-destructive-test X-ray equipment, CdTe detectors, Multi-spectral analysis**

I. Introduction

Food contamination is a regular occurrence all over the world. According to the Rapid Alert System for Food and Feed (RASFF) [1], 267 alerts about foreign bodies and contaminants found in foodstuff occurred in 2017, with a trend that has not been decreasing in the last 5 years. Among the broad range of technologies nowadays available for food inspection, X-ray detection machines represent by far the best solution, due to their ability to both spot a much wider range of contaminants and also inspect products at different stages of their production process. Despite this, the existing X-ray technologies are currently not able to completely solve the issue of contaminated food as they can detect high density foreign bodies, such as metal, lead, stones, bones and glass, while they fail in detecting low density contaminants made of a wide number of materials including plastic, wood, organic and, in general, other small unwanted foreign bodies made of very-light materials which accidentally end up in the products during their treatment on the production lines. With the aim to improve the current state of art in the field of industrial controls for food products, we have thus developed XSpectra® [2], a proprietary and novel X-ray inspection technology able to detect in real-time both low- and high-density contaminants in foodstuff. In the following paragraphs, the architecture of XSpectra® and some experimental results will be presented.

II. XSpectra® Requirements

Figure 1 shows a simplified drawing of a typical X-ray inspection system operating on a production line. An X-ray tube generates a blade-like photons-beam that irradiates the products moving by means of the conveyor belt of the line. The beam interacts with the products and is then collected by an X-ray detector for spectroscopic images reconstruction and processing. Conventional X-ray inspection machines, available today in the food market, work by just merely counting the photons in overall received by the detector (single-energy approach) or at most distinguishing those received in a couple of energy windows (dual-energy approach). XSpectra® has instead been designed in order to perform a real-time multi-spectral analysis, up to 1024 energy bands, with the specific goal to be able to also detect the low-density contaminants that are nowadays invisible; this requires XSpectra® to be sensitive to photon energies well below 20 keV. The high speed of the conveyor belts

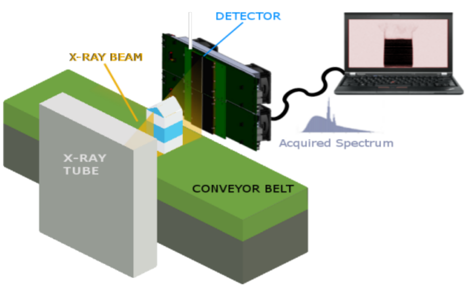

Figure 1. Simplified drawing of a real-time X-ray inspection system on a production line

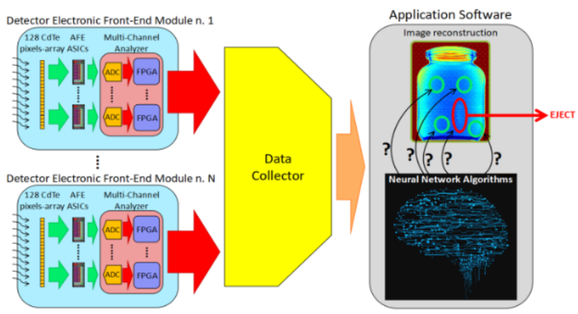

Figure 2. Simplified blocks schematic of XSpectra®

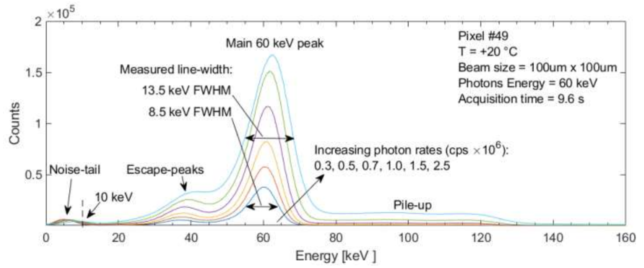

Figure 3. Spectrum at temperature T = +20 °C obtained by irradiating one pixel with a 100 µm × 100 µm area beam of 60 keV photons incident on its geometrical center at rates from 0.3×10^6 up to 2.5×10^6 cps.

typically adopted on production lines in the food market (up to 1 m/s) requires the use of high photon fluxes in order to collect spectra with a sufficient statistics; this requires XSpectra® to have spectroscopic capabilities up to rates of several millions of photons per second per pixel. Finally, XSpectra® must be also able to work at photons energies up to 130 keV. Putting together all such requirements, makes the XSpectra® design a real challenge.

III. XSpectra® Architecture

Figure 2 shows a simplified blocks schematic of XSpectra®. The first macro block is the Detector Electronic Front-End, which has a modular architecture. Each module comprises a CdTe linear-array of 128 pixels - with 0.8 mm pitch - which detects the photons emitted by the X-ray source after having passed through the scanned product. The signals of each pixel are read-out by a multi-channel full-custom Analog Front-End Application Specific Integrated Circuit (AFE-ASIC), realized in CMOS technology and developed in collaboration with Politecnico di Milano. The AFE-ASIC performs the very first analog processing on the signals and has been designed in order to obtain the challenging best compromise in terms of industrial reliability, low-power, high photon-rate and low-noise capabilities. The ASICs feed the Multi Channel Analyzer (MCA) that is composed by a high sampling-rate Analog to Digital Converter (ADC) followed by a FPGA-based full-custom Digital Signal Processor. Each MCA reconstructs the energy spectrum of the X-ray radiation detected by its own 128-pixels array and transfers it to the Data Collector. This last, which constitutes the second macro-block of the system, collects the data-streams produced by all the MCAs and delivers them to the Application Software, which is the third and last macro-block. The Application Software temporally re-orders the data delivered by all the MCAs and processes them by means of advanced proprietary Neural Network algorithms to both reconstruct the product image and also detect the presence of eventual contaminants inside it. In case a contaminant is detected, an EJECT signal is generated to drive the line ejector which removes the product from the line belt.

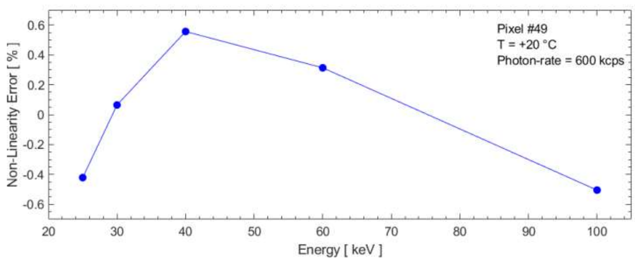

Figure 4. Non-linearity error measured between 25 keV and 100 keV.

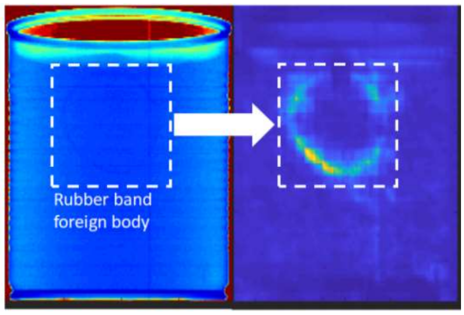

Figure 5. Scan of a chopped tomato aluminium can with a rubber band foreign body inside. Left-side: unprocessed radiographic image as produced by XSpectra®, in which the rubber-band is only barely noticeable. Right-side: image produced by XSpectra® algorithms, in which the rubber-band contaminant is fully detected.

IV. Experimental Results

XSpectra® modules have been experimentally characterized at beam line BM05 of the European Synchrotron Radiation Facility (ESRF) in Grenoble (France). The measurements have been performed at temperature T = +20 °C by irradiating a sub-set of the overall 128 pixels-array by means of a 100 µm × 100 µm area beam of monochromatic photons, at different energies and rates, centered in the middle of the tested pixels. Figure 3 shows the raw spectra obtained with one of the tested pixels by irradiating it with 60 keV photons at incoming rates ranging from 0.3×10^6 counts-per-second (cps) up to 2.5×10^6 cps. The main 60 keV line width resulted to be 8.5 keV FWHM at the lowest-rate measurement condition and 13.5 keV FWHM at the highest one. The escape-peaks and pile-up regions can be clearly appreciated. As can be seen in the figure, the system noise tail affects the lowest-energy part of the spectrum below about 10 keV at all the tested photon-rate conditions, thus making the spectral information fully usable by the algorithms approximately starting from such energy on. The non-linearity error of the system has been measured by irradiating the same subset of pixels by means of photons with energies between 25 keV and 100 keV. The result is reported in Figure 4 and shows as the error lies within ±0.5% in all the range. XSpectra® performances have also been extensively tested at the Xnext s.r.l. facility in Milano (Italy) [2] on many applicative cases directly required by worldwide companies operating in the food market. Such tests consisted in using XSpectra® at its full functionality to scan real food-products in search of real-case contaminants which still represent an issue in the food market as being still undetectable. Figure 5 shows, as an example, a chopped tomato aluminium can with a contaminant inside as analyzed by XSpectra®. The aluminium can is a cylinder of 7.5 cm diameter × 11 cm height with a side wall thickness of 1.5 mm. The contaminant is a circular rubber-band with 1 mm thickness × 5 mm width. The left-side of the figure shows the unprocessed radiographic image of the tomato can as produced by the system. The right-side of the figure shows the result produced by XSpectra® algorithms, in which the foreign body has been clearly detected.

V. References

[1] https://ec.europa.eu/food/safety/rasff/
[2] http://www.x-next.com/