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Status for NEXIM New X-ray Imaging Modalities for safe and high quality food

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Value for industry

- New X-ray techniques based on grating based imaging (GBI) provide imaging modalities that allow objects that have similar absorption profiles, but different micro-structures to be distinguished from one another.
- GBI has shown great potential for investigating how heat treatment affects the final quality of meat products. The non-destructive technique allows for imaging the same sample in a raw and cooked state and the full 3D volume can be quantitatively analyzed to reveal new parameters relating to the final quality.
- Additionally GBI has proven capable of revealing foreign objects not detected by conventional X-ray absorption techniques. These materials include cartilage, paper, wood fragments, insects and plastic. Implementing GBI into an in-line scanning process could therefore greatly increase the detection of foreign objects, meeting the consumer demands of safe and high quality food.

Background

The main objectives of the NEXIM project are to develop the novel X-ray grating interferometry technique (Weitkamp *et al.* 2005; Pfeiffer *et al.* 2008) specifically towards food application and to identify the areas within the Danish food industry with the highest technological and commercial impact. The main focuses are determined to be threefold:

- 1) Improving the detectability of low density foreign bodies incidentally present in food products.
- 2) Development of new modalities for assessment of quality traits in food production, for instance connective tissue and fatty acid composition.
- 3) Develop a proof-of-principle of a conveyor belt solution that can form the basis for real product development.

In the past year the NEXIM project has focused on these three objectives, studying the applicability of GBI to meat quality assessment and foreign object detection. Some efforts have been put to developing laboratory-based setups further towards an in-line scanning system. Additionally, close co-operation with industrial partners has further emphasized the need for new techniques for quality control, product development and foreign object detection.

Why work is needed

In the food production industry, conventional X-ray scanning offers penetrating power to monitor the inside of food. X-rays can provide high contrast between fat and meat and detect foreign objects that have a sufficient difference in attenuation length from the food product. The subtle differences in soft material and foreign objects such as cartilage, wood chips, plastic fragments, insects and paper make these materials hard to distinguish using conventional X-ray techniques.

A recent survey of Japanese customer complaints on contaminants in food (Takashi *et al.* 2009) showed that these objects are the most challenging foreign materials, which still cannot be adequately detected. Further, within meat science there is a great interest in determining the effects of heat treatment and different temperature profiles on the final eating quality of meat. However, no current method has the capability of revealing 3D structural properties of soft materials such as connective tissue due to the similar attenuation properties of meat.

However, phase contrast and dark-field imaging have been shown to provide superior contrast in a study of pork rind and fat (Jensen *et al.* 2011), and potential for improved segmentation of pork back fat and beef muscle (Nielsen *et al.* 2012).

GBI provides means to both increase the detection of foreign objects and to study structural changes of food products in 3D non-destructively, such that the same sample can be measured before and after heat treatment. Until now, GBI has been performed mainly at synchrotron sources or using laboratory-setups. Neither is suitable to an industrial setting due to complexity, acquisition times and cost. Further development of the method towards an industrial standard is therefore needed, and the NEXIM project has focused its attention to bringing GBI closer to an industrial in-line scanning system.

The methods used

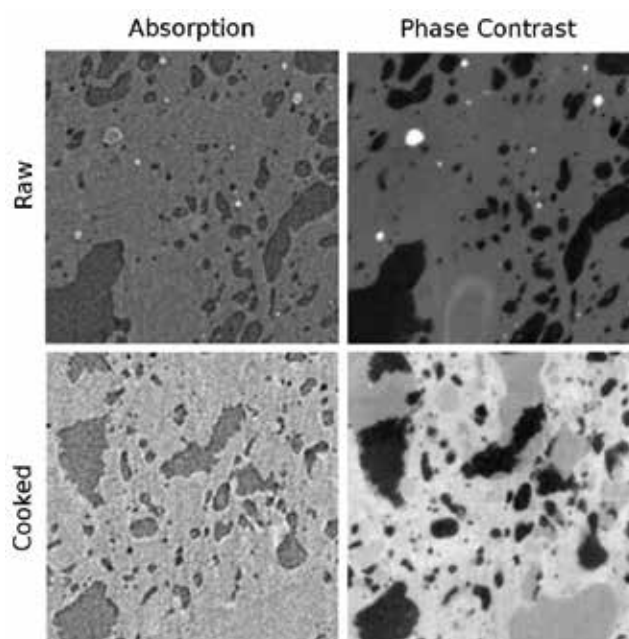
In order to determine how the industry can best benefit from GBI, data has been gathered both from synchrotrons and laboratory-based setups. This serves as an essential pre-study to whether the goal of achieving an industrial standard for GBI will be feasible. In the past year the main focus has been set on investigating the effects of heat treatment on meat products, and both whole muscle and meat emulsions were imaged at the TOMCAT beamline at the Paul Scherrer Institute, PSI, Switzerland. The full volumes obtained were $1720 \times 1720 \times 513$ voxels with an effective voxel size of $7.4 \mu\text{m} \times 7.4 \mu\text{m} \times 7.4 \mu\text{m}$.

Additionally the sensitivity of GBI to foreign objects has been investigated at the laboratory-based setup at Niels Bohr Institute using a rotating anode tube source. Several food products have been imaged including minced meat, sour cream, potatoes and spring rolls with foreign objects such as folded paper, cigarette stubs, broken glass, insects and string. The acquired data was 195×487 pixels with an effective pixel size at sample of $126 \mu\text{m} \times 126 \mu\text{m}$.

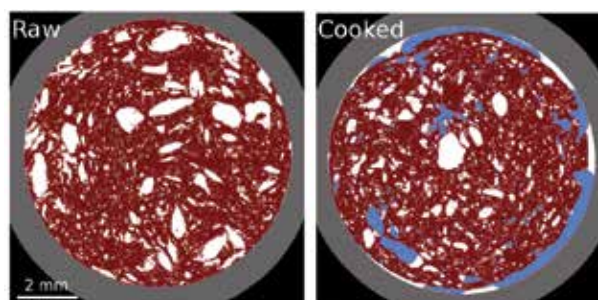
Image segmentation has played a large role in the analysis of acquired data, and multivariate algorithms have been developed to simultaneously exploit the three imaging modalities obtained from GBI. Conventional X-ray analysis typically relies on the Hounsfield scale, which is a quantitative scale describing radio density, for classification of sample materials. Since GBI also measures the electron density and scattering properties of the imaged sample, new means to classify materials is needed. Here, the multivariate nature of the data has been exploited and is modeled as a mixture of multivariate Gaussians using an expectation-maximization (EM) algorithm (Dempster *et al.* 1977). Additionally, to exploit the spatial nature of the data, Markov random fields (MRF) using graph cuts (Boykov *et al.* 2001) have been applied and further extended to obtain good segmentation results of fine structures such as connective tissue.

The results obtained

The obtained results from TOMCAT can be seen in Figure 1 where a partial slice of the meat emulsions from the absorption and phase contrast modalities are shown. The contrast obtained by measuring the refraction (phase contrast) is superior, and the expressible fluid in the emulsion can be distinguished from the protein network. As the GBI method allows for obtaining data non-destructively for the entire sample volume, the same samples are imaged before and after heat treatment. This introduces the opportunity to quantitatively determine parameters indicating the final product quality.



a) Meat emulsions.



b) Segmentation results.

Figure 1. In a) tomographic slices of meat emulsions from the absorption and phase contrast modalities are shown. The emulsions are shown in both the raw and cooked state. The phase gives clearly a higher contrast, revealing the expressible fluid in the cooked meat emulsion. In b) the segmentation results from modeling the data with the EM and MRF algorithms is shown. Reprinted from (Einarsdottir *et al.* 2013).

The stability of meat emulsions was studied where the use of two lipids types in the emulsions was analyzed and compared (Einarsdottir *et al.* 2013, Miklos *et al.* 2013). Table 1 shows the percent object volumes for the sample ingredients in the emulsion samples. The multivariate segmentation method was capable of classifying the expressible fluid making it possible to determine the cooking loss of the emulsion. These results were presented at the InsideFood Symposium 2013 in Leuven, Belgium.

Parameter	Lard raw	Lard cooked
Protein (%)	73.9	73.9
Water (%)	-	15.6
Fat (%)	25.3	25.0
Salt (%)	0.8	-

Table 1. Percent object volumes for the ingredients in the emulsion samples. The protein phase includes both protein and moisture which could not be separated due to resolution limitations.

In (Nielsen *et al.* 2013) the novel GBI approach showed how dark-field imaging revealed organic foreign materials in minced meat and sour cream. The results are shown in Figure 2. Here the absorption modality only reveals the broken glass in the minced meat. The cigarette stub is discernible in the phase contrast modality and the paper, cigarette and insects are all clearly visible in the dark-field modality.

These results proved promising, and further studies showed that wood chips in potatoes and string in spring rolls can be easily identified. Further empirical studies are needed to determine the size detection limit.

Here, the capability of the dark-field modality to reveal sub-scattering information (Pfeiffer *et al.* 2008) may prove useful in identifying foreign objects smaller than the detector resolution. Furthermore, segmentation methods based on texture analysis are in the pipeline for future work.

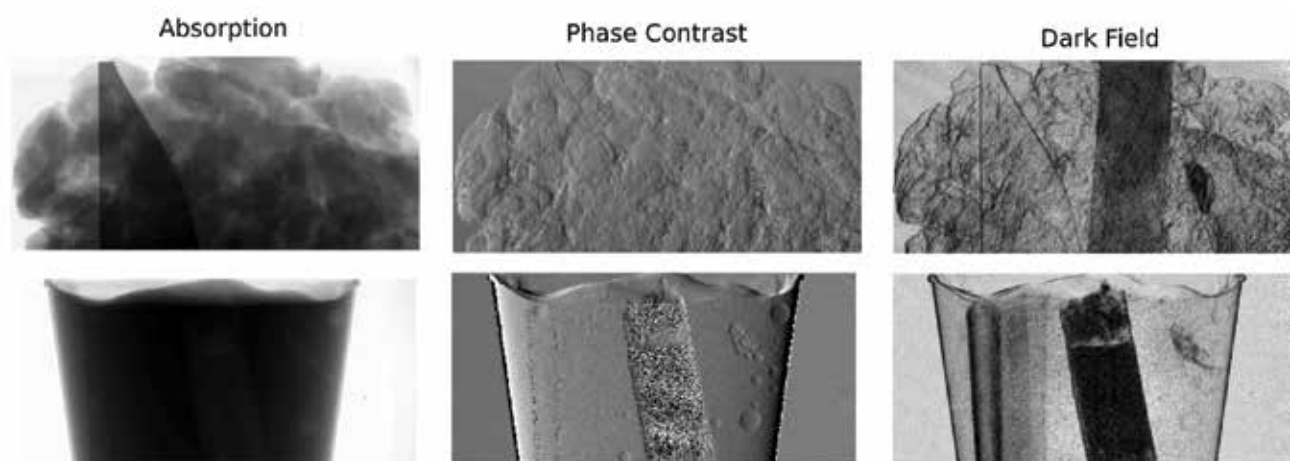


Figure 2: The results from GBI of organic foreign bodies placed in food products. Top: Minced meat with broken glass (left), 4 layers of paper (middle) and ladybug (right). Bottom: Sour cream with 8 layers of paper (left), a cigarette butt (middle) and a fly (right). Reprinted from (Nielsen *et al.* 2013)

The scientific conclusions

Food quality assessment

Studies from the preceding year have shown that GBI is a feasible method to determine cooking loss and structural changes of connective tissue in meat products after heat treatment.

Foreign object detection

Proof-of-principle experiments have demonstrated some of the potentials of GBI as a promising emerging modality for detection of organic and other 'hard-to-find' foreign bodies in food products.

In-line scanning

Some attempts have been made to further develop a laboratory-based setup towards an industrial solution. A scanning type procedure has been tested with good results.

Next steps

Several obstacles are still to be overcome before GBI becomes a feasible option for industrial use. Here acquisition times and instrument sensitivity play a big role. Future studies will focus on time resolved GBI, further development of segmentation methods and texture analysis

Acknowledgements

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