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Novelty detection of foreign objects in food using multi-modal X-ray imaging

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ABSTRACT

In this paper we demonstrate a method for novelty detection of foreign objects in food products using grating-based multimodal X-ray imaging. With this imaging technique three modalities are available with pixel correspondence, enhancing organic materials such as wood chips, insects and soft plastics not detectable by conventional X-ray absorption radiography. We conduct experiments, where several food products are imaged with common foreign objects typically found in the food processing industry. To evaluate the benefit from using this multi-contrast X-ray technique over conventional X-ray absorption imaging, a novelty detection scheme based on well known image- and statistical analysis techniques is proposed. The results show that the presented method gives superior recognition results and highlights the advantage of grating-based imaging.

1. Introduction

X-rays are increasingly used in the food production industry for quality control inspection (Haff & Toyofuku, 2008; Kwon, Lee, & Kim, 2008; Mery et al., 2011; Zwiggelaar, Bull, Mooney, & Czarnes, 1997). They provide a non-destructive method to quantitatively measure food quality traits and detect foreign objects. Foreign objects can be introduced to food products for instance from raw materials or due to malfunctioning of the production line. The detection of foreign objects is not only important in regards to consumer satisfaction, it is also required by regulations to secure consumer safety. In a recent survey of Japanese consumer complaints on contaminants in food, it was revealed that the most challenging foreign materials, which still cannot be adequately detected by conventional X-ray systems, are paper, wood chips, plastic, cartilage and insects (Takashi, 2009). Table 1 shows the contaminants most frequently complained about, and the difficulty level of detecting them using conventional X-ray techniques. Several hazardous contaminants such as blade chips, bones and glass fragments are classified at difficulty level medium, highlighting the need for a more effective detection method.

Recent advances in X-ray imaging have introduced new imaging modalities such as phase contrast and dark field contrast, obtainable by grating-based interferometry (Bech et al., 2010a; Pfeiffer, Weitkamp, Bunk, & David, 2006; Pfeiffer et al., 2008). These modalities have shown to produce enhanced contrast capabilities over the typical absorption X-ray modality (Bech et al., 2010b; Jensen et al., 2011; Pfeiffer et al., 2007). The grating-based approach allows for obtaining three imaging modalities simultaneously, with pixel correspondence. The modalities consist of conventional absorption X-ray, phase contrast imaging and dark-field imaging. A

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Table 1
Japanese survey results for consumer contaminant complaints (Takashi, 2009) and the level of difficulty of detection with absorption X-ray techniques.

Contaminant	Percentage (%)	Difficulty of detection by X-ray
Insects	24.5	Difficult
Bone (calcified only)	15.2	Medium
Unclear	14.1	N/A
Metal piece	7.3	Easy
Hairs	6.6	Difficult
Needles, wires etc.	6.5	Easy
Plastic and rubber	5.3	Medium
Glass fragments	3.9	Medium
Stone and sand	3.0	Easy
Paper, threads etc.	2.1	Difficult
Vinyl	2.0	Difficult
Fly	1.8	Difficult
Wood chips	1.5	Difficult
Blade chips	1.2	Medium
Staples	1.0	Easy
Rat excrement	0.9	Difficult

recent study (Nielsen, Lauridsen, Christensen, & Feidenhans'l, 2013) presented a novel approach for visual detection of organic foreign bodies such as paper and insects in food products using X-ray dark-field imaging. Here, the dark-field modality gave larger contrast-to-noise ratios than absorption radiography for organic foreign objects.

In this paper we build upon these results and provide an extensive and thorough analysis of the novelty detection capabilities of the higher contrast obtained from grating-based X-ray imaging. The purpose of the study is to compare the detection rates between the multimodal X-ray data and conventional absorption X-ray. Additionally, a comparison of detection rates when using only intensity based information versus including texture features is conducted. A novelty detection scheme is developed based on image- and statistical analysis techniques. The algorithm first computes texture features of the image modalities. Next, a model of each food product is created by fitting a Gaussian Mixture Model (GMM) to either the image intensities alone or by including the texture features. Images with foreign bodies are then evaluated by calculating the Mahalanobis distance to the food models for all image pixels. Optimal thresholds for detecting foreign objects are then chosen to minimize false positives and maximize the true positive rate. To determine the gain of using grating-based imaging over conventional absorption radiography, the detection results of both methods are compared by the rates of detected foreign objects versus false positives. This is done both pixel-wise and on an object count bases. To test the novelty detection capabilities of the algorithm we investigate a wide range of foreign bodies of varying sizes in seven different food products. The chosen foreign bodies include objects typically found in the food processing industry that have proven problematic to detect using conventional X-ray techniques.

2. Materials and methods

2.1. Grating-based X-ray imaging

The grating-based interferometer is described in detail in Pfeiffer et al. (2006), (2008). The imaging modalities obtained by grating-based imaging (GBI) consist of three types of physical interactions — attenuation, refraction and scattering. These modalities are refered to as absorption, phase contrast and dark-field imaging, respectively. The setup for GBI is shown in Fig. 1. The phase grating produces a periodic intensity modulation consisting of periodic fringes transverse to the beam direction. The change in position, mean value and amplitude of the periodic fringes can be

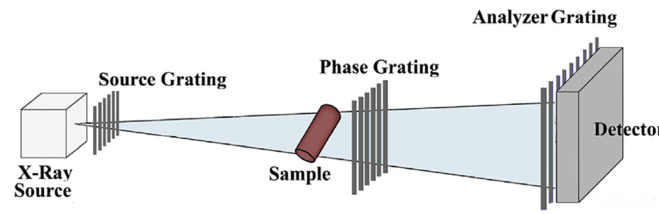

Fig. 1. A schematic of a X-ray radiography setup using a grating interferometer.

probed using the analyzer grating by moving the source grating in steps through the period in the pattern while recording an image at each step. From this series of scans, the absorption, refraction and small-angle scattering can be recorded by a detector using the same exposures, giving an inherent pixel correspondence.

2.2. Data set

The data set used for training and testing the detection algorithm in this study consists of images of seven different food products (minced meat, steak, turkey schnitzel, salami slices, sliced cheese, wheat bread and rye bread). These products were chosen based on their range in texture homogeneity. The foreign objects used were chosen based on a survey conducted with industrial collaborators within the research project. Table 2 shows the list of foreign objects, along with their density and size. Fig. 2 shows the foreign objects in the three different size groups. In the experiment, a total of 7 food products where imaged with 8 different foreign object materials. Each image contains all the foreign objects from a single size group, giving in total 7 × 3 X-ray exposures, each exposure consisting of the three image modalities.

Projection images were obtained at a laboratory GBI setup located at the Chair of Biomedical Physics at the Technische Universität München. The effective energy used was 25 keV, with 9 steps of the phase grating and integration time of 2 s. From the raw data, the three imaging modalities were obtained by sine fitting as described in Bech et al. (2010c). The setup is described in detail in Scherer et al. (2014). The obtained image resolution is 800 × 800 pixels.

2.3. Detection algorithm

For a novelty detection task, the classification problem is concerned with identifying whether a pattern is part of the data or is in fact unknown. In other words it is sought to assign an ‘abnormal’ label to foreign objects within known ‘normal’ food products. Therefore, novelty detection only needs the known class for training purposes and usually a distance measure and a threshold for decision making. Both intensity and texture features are

Table 2
Foreign objects used to test the detection algorithm. Both the approximate density and thickness of each object is given.

Type	Density (g/cm^2)	Thickness (mm)		
		Size 1	Size 2	Size 3
Glass	2.62	5	3	2
Metal	3.82 to 7.82	2	1	0.5
Wood	0.63	6	4	2
Insects	0.12 to 0.47	5	3	2
Hard plastic	0.66	6	3	2
Soft plastic	0.30	5	3	2
Rubber	1.21	4	3	2
Stones	2.23 to 2.50	6	4	3