High Contrast Images of Defects in Food Package Seals

Catherine H. Frazier, Ayhan Ozguler, Scott A. Morris, and William D. O'Brien, Jr.

C. H. Frazier and W.D. O'Brien, Bioacoustics Research Laboratory, Department of Electrical and Computer Engineering, University of Illinois, 405 N. Mathews Ave., Urbana, IL 61801.

A. Ozguler and S.A. Morris, Department of Food Science and Human Nutrition, University of Illinois, 1304 W. Pennsylvania Ave., Urbana, IL 61801.

Abstract— **Previous work to detect channels in packaging seals using pulse-echo ultrasound inspired the Backscattered Amplitude Integral (BAI) imaging technique [1], which could reliably identify channels with diameters larger than 15 μm at a center frequency of 17.3 MHz (λ = 86 μm). However smaller channels ($\approx$ 6μm in diameter) can be easily revealed by processing the data according to a new imaging technique that displays a single time-gated pressure value from the received (not envelope-detected) rf waveform at each transducer position, that is, an rf sample image (RFS). The applicability of this technique for detecting channel defects is demonstrated for plastic and aluminum foil trilaminate films with 6, 10, 15, 38, 50, 75, and 100 μm channels filled with water or air. The images are formed with a focused ultrasound transducer (17.3 MHz, 6.35 mm in diameter, f/2, 173 μm -6 dB pulse-echo lateral beamwidth at the focus) scanned over a rectangular grid, keeping the package in the focus. Subwavelength channel defects as small as 6 μm can be easily detected but appear larger than 150 μm wide, according to the focal point size of the transducer. The time-gate used to create an image is chosen based on where the maximum reflection from the back surface of the material is expected. Images created with the RFS technique demonstrate higher contrast than images formed using the BAI or ultrathin C-mode (UTC) techniques. However, RFS imaging also has higher probability of not detecting a channel that is present.**

I. Introduction

An important part of the packaging process is the detection of flaws in the package's seal. Previous researchers have shown that channels in packaging seals can be detected using the Backscattered Amplitude Integral (BAI) imaging technique [1]. BAI images display the integral of the envelope-detected rf signal at each transducer position over a rectangular scan area. Channels with diameters larger than 15 μm can be detected reliably using this technique at a center frequency of 17.3 MHz. However, at the same center frequency, 6 μm-diameter channels can be easily revealed by displaying for each transducer position a single time-gated pressure value of the received rf waveform. Since no envelope detection is required, images are created much faster than with the BAI technique, and therefore this new method is better suited for a production line.

For rf sample (RFS) imaging to be useful, a method must be given for choosing the point from each waveform for display, and images created using that point must reliably show channels when they exist. We will discuss a procedure for choosing the time-gate; we will compare the new technique to other imaging methods on the basis of image contrast; and we will discuss the new technique in terms of how reliably channels are detected.

II. Data Collection

The materials and data collection method are discussed extensively in [2]; therefore, these details will be mentioned only briefly here. Two types of packaging film are examined, each with three layers of material. The first type of film is plastic trilaminate with a layer of polypropylene (80 μm, c = 2660 m/s), a layer of polyvinylidene chloride (PVDC) (15 μm, c = 2380 m/s), and a layer of oriented nylon (15 μm, c=2600 m/s). The overall film is 110 μm thick with an average speed of 2380 m/s. The second type of packaging film is an aluminum foil trilaminate with a layer of polypropylene (c = 2660 m/s), a layer of aluminum foil (c = 6420 m/s), and a layer of polyester (c = 1950 m/s). The individual material thicknesses for this material are unknown. The overall thickness of this film is 120 μm, and the average speed is 2460 m/s.

Defects are created by fusing together two films with a tungsten wire in between using an automatic heat sealer and removing the wire after the seal has cooled. The channel sizes are 6, 10, 15, 38, 50, 75, and 100 μm. Defect sizes have been confirmed using a light transmission micrscope. In general, the defects are elliptical in shape; however, their sizes closely resemble the size of the wires used to create them [2]. Therefore, we refer only to the size of the wire when describing the channel size.

A three-dimensional data set is collected using a nominal 20-MHz focused transducer operating with an actual center frequency of 17.3 MHz (6.35 mm in diameter, f/2, 173 μm -6 dB pulse-echo lateral beamwidth at the focus). The transducer is shock-excited by a Panametrics pulser-receiver with a 300 V monocycle pulse. The transducer is scanned in two directions. The surface of the packaging material is perpendicular to the beam axis and the sample is kept in the focus of the transducer throughout the scan. The signal is captured by a LeCroy digitizing oscilloscope with a sampling rate of 500 MHz, keeping 512 samples for each transducer position.

III. Image Formation

In order to create the images, the waveforms at each transducer position are first justified in time to correct for flaws in the surface of the package, which would change the absolute time to the first reflection for each waveform. This justification is accomplished by aligning the signals according to when the pressure reaches its maximum. This method takes advantage of the fact that the first reflection from the surface of the package will have the greatest amplitude.

To create rf sample images, a single sample of the time-justified waveform is kept. Due to the sampling process, each sample of the waveform represents an integral of the analog waveform over a 10 ps window.

For comparison, we create ultrathin C-mode images (UTC). For these images, a reduced data set is created by retaining 256 samples of each waveform, starting with the maximum received pressure. The Hilbert transform is performed on the 256 points retained from each waveform. Then the magnitude of a single point for each envelope-detected waveform is kept to create the image. Finally, we also compare to BAI images, which are formed by integrating the envelope-detected signals at each transducer position.

IV. Choosing the Time-Gate

For the RFS imaging method to be useful, it must be possible to detect channels of all sizes by creating a few images for each data set. For large- and moderate-sized channels (compared to a wavelength), we look for the channel where the reflection from the back surface of the package would be if there were no channel. For these channels, the acoustic path through the channel is significantly longer than the path with no channel so that the back reflection is clearly delayed. We use a time-gate that selects the point where the reflection from the back surface reaches its maximum when there is no channel.

We look for the reflection from the back surface at

$$s = \frac{4d}{c_{ave}} f_{samp} \tag{1}$$

where d is the thickness of one layer of film, c_{ave} is the average speed of sound through the material, and f_{samp} is the sampling rate. For the trilaminate material, the total thickness of the material is 110 μm, and the average speed through the material is 2380 m/s. Our sampling rate is 500 MHz. Therefore, we look for the reflection from the back surface at sample 92. For the aluminum foil material, the measured thickness of the material is 120 μm, and the average speed is 2460 m/s, so we look for the reflection from the back at sample 98.

For small channels, using a time gate for the reflection from the back surface occasionally reveals the channel; however, another time gate can also be used. At the location of the channel, between the two layers of film, there is a slightly higher reflection due to the change in impedance from the polypropylene to the material in the channel. Therefore, another time-gate to form the image chooses a point at the location of the boundary between the two fused layers of packaging material. Using the values stated above for the trilaminate and aluminum foil packaging materials, we look for the boundary reflections at samples 46 and 49, respectively.

V. Quantifying Contrast

ΔBAI is the quantity used to describe the contrast of the images. Raum et al, [1] define ΔBAI as

$$\Delta BAI = BAI_{background} - BAI_{channel} \tag{2}$$

where $BAI_{background}$ is the average BAI value (integrated pressure amplitude) over a region with no channel and $BAI_{channel}$ is the average BAI value at the location of the channel. For the RFS images, we use the time-gated pressure value for each region rather than the BAI values. And for the UTC images, we use the of the pressure amplitude samples. Because we use the envelope-detected signal for UTC and BAI mode images, the minimum possible pixel value is zero. Because we have normalized the pressure values, the maximum pixel value is one. Therefore ΔBAI can range from -1 to 1. ΔBAI is negative when the channel is lighter than the background. ΔBAI of zero implies that there is no contrast and therefore no channel can be detected. In this study ΔBAI is calculated for normalized pixel values so that contrast in images can be compared. In [2], nonnormalized ΔBAI values are calculated so that differences between material types can be observed.

For RFS images, the pixel values are normalized to the pixel with the highest magnitude, which is either positive or negative. Therefore, the pixel values can range between -1 and 1, and ΔBAI can range between -2 and 2. However, in practice, the maximum and minimum time-gated pressure values used to create a single image generally have the same sign. Therefore, ΔBAI actually ranges between -1 and 1. To make the comparison between imaging techniques, pixel values for the RFS images are forced to be within a unit range by clamping the minimum pixel value.

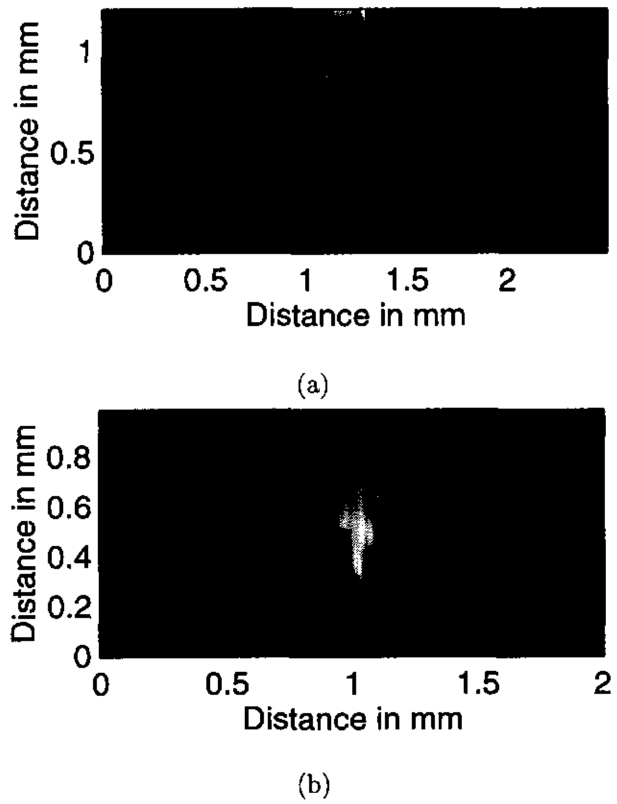

Figure 1: Rf sample images for water channels in plastic trilaminate film, (a) 75 μm, sample 92, (b) 6 μm, sample 46.

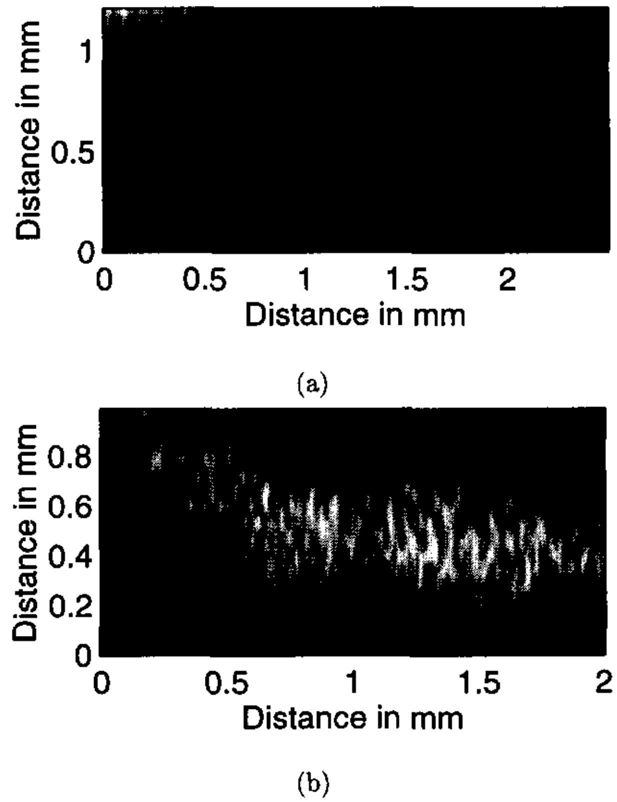

Figure 2: BAI images for channels displayed in Figure 1, (a) 75 μm, (b) 6 μm.

VI. Results

Four or five data sets were collected for each combination of channel size, type of packaging film, and material in the channel. RFS and BAI images are shown for two channels in Figures 1 and 2, respectively. The larger channel is visible for both types of images; however, the smaller channel is detected in only the rf sample image. Both channels are also visible in the UTC images (not shown.)

The BAI imaging technique revealed 100 % of channels 38 μm or larger. The UTC imaging technique revealed 100 % of channels 10 μm or larger for the plastic trilaminate film and 15 μm or larger for the aluminum foil trilaminate film. The RFS imaging technique revealed 100 % of channels 15 μm or larger for the plastic trilaminate film and 50 μm or larger for the aluminum foil trilaminate film. Remaining detection rates are shown in Table 1.

The average ΔBAI values for channels detected are shown in Figures 3 and 4 for the water-filled channels. The RFS and UTC curves have sharper changes in the curves because each uses a single point to create an image. The time-gate chosen for the plastic trilaminate film lead to high detection rates and high contrast using RFS imaging. For the aluminum foil film, the point chosen happened to correspond to where the two waveforms (through the channel and not through) crossed, and the images had low contrast. However, using experimentally determined points, (sample 105 for large channels and 55 for small channels) all of the channels could be detected except for one 75-μm channel filled with water.

VII. Conclusions

With rf sample imaging, we are able to detect channels as small as 6 μm in diameter easily using pulse-echo ultrasound with a 17.3-MHz transducer. This new imaging method has been applied to a special imaging problem for which we have significant information about the material and the location of the channel, which must be between the two layers of film. Given this *a priori* knowledge, we are able to select only a few time-gates to create images.

BAI mode imaging allows us to detect channels as small as 6 μm; however, we can only detect down to 38 μm reliably. UTC imaging allows us to choose a single point to display and then detect 10 μm channels reliably. However, there is no computational advantage to using UTC imaging rather than BAI imaging. Both require envelope-detection. Rf sample imaging allows us to cre-

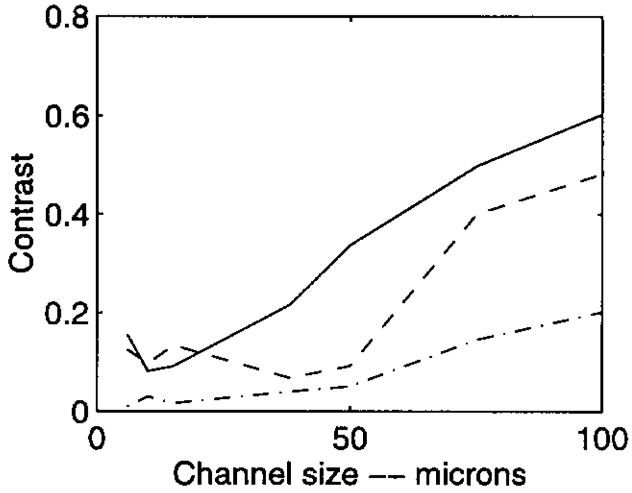

Figure 3: Average contrast for water-filled channels in plastic trilaminate film, rf sample (solid line), UTC (dashed line), BAI (dash-dotted line).

ate high contrast images very fast; however, because of the oscillations of the carrier signal, the location of the highest contrast is more difficult to find, and therefore channels will go undetected more often.

In this study, a perscription was given for finding an appropriate time-gate. However, in practice the time-gate can be found experimentally. For a single material, the location of the time gate used to create images was stable; therefore, a time-gate for each material can be chosen using a calibration data set.

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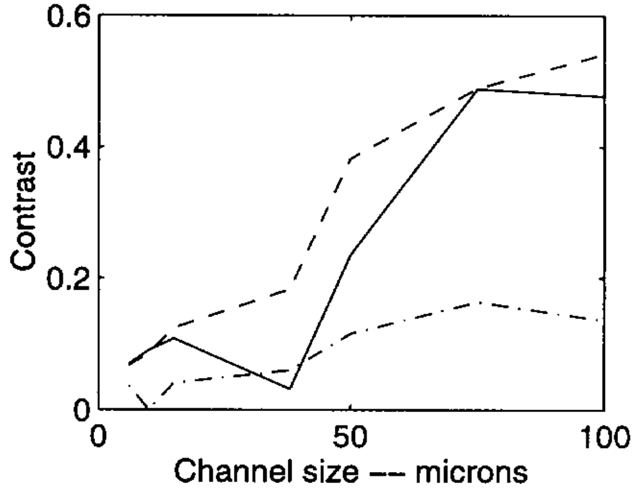

Figure 4: Average contrast for water-filled channels in aluminum foil trilaminate film, rf sample (solid line), UTC (dashed line), BAI (dash-dotted line).

Table 1: Evaluation of robustness based on the detection rate. 100% of channels not listed in this table were detected by all three imaging methods.

Detection rate				
film/ channel	size	BAI %	UTC %	rf sample %
plastic/ water	15	80	100	100
	10	80	100	100
	6	75	75	100
plastic/ air	15	80	100	100
	10	20	100	80
	6	0	50	50
foil/ water	38	100	100	60
	15	40	100	100
	10	0	60	80
	6	50	50	25
foil/ air	15	20	100	80
	10	20	80	60
	6	100	50	25