MORPHOLOGICAL IMAGE PROCESSING FOR ECHO DETECTION ON ULTRASONIC SIGNALS: AN APPLICATION TO FOREIGN BODIES DETECTION IN THE ALIMENTARY INDUSTRY

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ABSTRACT

Echo detection on time-varying signals is a typical problem of signal processing. A not so typical application of this problem is the detection of foreign bodies in the alimentary industry. In this work we are going to present some results of a project whose objective was to develop an ultrasonic automatic system for detection of foreign bodies.

The algorithm presented merge some ideas of time frequency representation (TFR) and morphological image processing to get an easy to implement and highly customizable algorithm that could be applied to many different products and situations.

1. INTRODUCTION

Time frequency representations (TFR) are frequently used for detecting echoes on radar, sonar and ultrasonic applications [1]. The Fourier transform is of limited use for the analysis of time-varying signals as it does not provide easily accessible information about the time localization of given signal frequencies. TFRs map a one-dimensional signal in time to a two-dimensional function in time and frequency and are capable of displaying the temporal localization of the spectral components of a signal along its instantaneous frequency or group delay. It is then easy to devise tests that look for the presence/ absence of given frequencies in the time varying signal. In this work we are going to focus on the very specific problem of detecting echoes on ultrasonic signals. The underlying problem is the detection of foreign bodies in the alimentary industry by means of ultrasonic inspection.

This work is organized as follows. In the next section we will analize the problem from the signal processing point of view: modelation, echo characterization,etc. After that in section 3 we will describe the proposed algorithm. Finally in section 4 the real application will be presented and results applied to real signals to obtain minimum detected foreign body size.

2. ULTRASONIC ECHO DETECTION ON HIGHLY ATTENUATING AND/OR NON HOMOGENEOUS MATERIALS

The ultrasonic inspection of foreign bodies in alimentary industry is frequently performed in pulse echo mode [2] (similar to a radar or sonar navigation system). When an ultrasound is transmitted to a clear portion, an echo signal from the back surface of the part can be received. When a small flaw (or foreign body) is on the path of the ultrasound beam, echo signals will appear ahead of the back surface echo in the time domain and the back surface echo will disappear if the flaw is large enough to intercept most of the beam from the transducer. Signals recorded this way are time-varying signals called A-Scan. There are some situations where the flaw echoes or even backwall echoes are difficult to see in time domain. This behaviour normally appears on highly attenuating and/or non homogeneous materials. Two are the effects that affect A-Scan from the signal processing point of view:

- Selective attenuation of higher frequencies. High spectral contents tend to disappear as time increases.
- A-Scans are contaminated with structural grain noise (due to scattering in non-homogeneous materials). Some alimentary industry products present heterogeneous food texture that produces multiple reflections giving as a result noisy A-Scans.

TFR can help to detect in this situations the presence of a flaw echo.

2.1 Signal processing modelling of the problem

A-Scans can be modeled as shown in figure 1 [3, 4, 5, 6, 7, 8], where central frequency of the bandpass filter $f_0(t)$ depends of time to resemble the selective attenuation of some materials and the flaw echo can be artificially introduced at any time.

As in many other echo detection algorithms [9] we are going to exploit that altought grain noise and foreign bodies echoes share central frequencies (see figure 2), the persistence in time and frequency is higher for the echoes comming from foreign bodies (and for backwall echo) than for grain noise. As we have previously stated, selective attenuation of some alimentary products alongside with the unknown nature of the foreign bodies makes it difficult to predict the central frequency of the foreign body echo.

Among all the possible alternatives of detection algorithms we have chosen to work with a binarized version of the TFR and apply morphological image processing. Altought this image processing approximation to a detector is computationally more complex it allows to exploit all the information about foreign bodies echoes (area, shape, proximity to other echoes, etc.).

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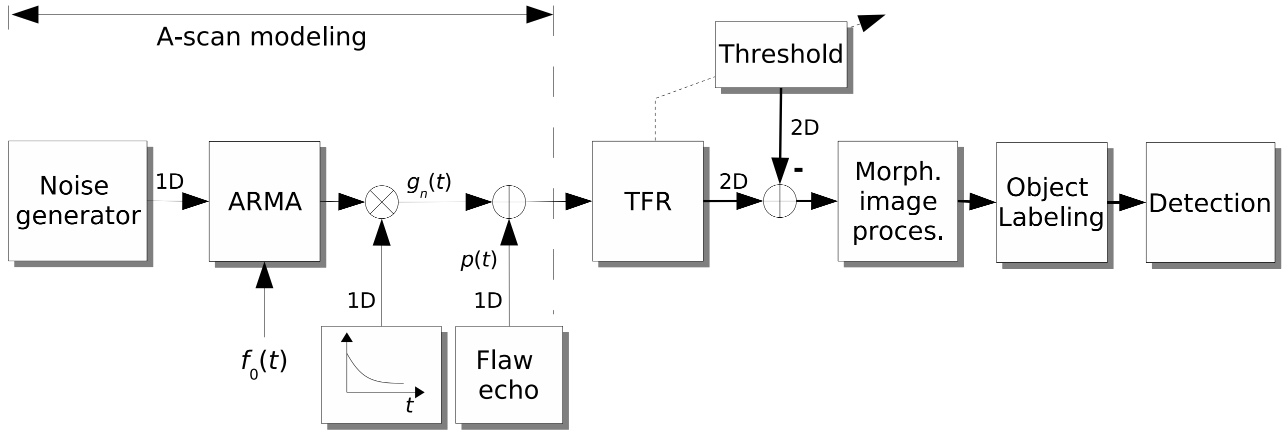

Figure 1: Signal processing modelation and proposed detection algorithm

3. PROPOSED ALGORITHM

The proposed algorithm can be seen at the right side of the figure 1 and is described as follows:

1. TFR of the A-Scan is calculated.
2. Envelope of the TFR is approximated using a 4th order polynomial.
3. This approximation (after a percentage scaling) is used as a threshold for binarizing the TFR.
4. Opening and closing of the resulting image is performed with an square 2x2 structuring element [10].
5. After labeling object selection and detection is done based on morphological criteria (area, shape,...)

3.1 Calibration: detection and false alarm probability

Simulations of the proposed model have been done for 500 Monte-Carlo runs with different values in threshold level an Signal to Noise Ratio. The Signal to Noise Ratio (SNR) has been locally estimated following equation 1 where the noise introduced in the model described in the figure 1 is K-type and $[t_0, t_1]$ is a time interval that includes the flaw echo. The foreign body echo has been captured from real meassures, scaled and introduced. The simulations can be seen on the figure 3 for detection probability and in figure 4 for false alarm ratio.

$$\widehat{SNR} = 10 \cdot log \left\{ \frac{\int_{t_0}^{t_1} p^2(t)dt}{\int_{t_0}^{t_1} g_n^2(t)dt} \right\} \quad (1)$$

4. FOREIGN BODIES DETECTION ON ALIMENTARY INDUSTRY BY ULTRASONIC INSPECTION

This work is part of a research project where a system for foreign bodies inspection on sauces and any other similar alimentary industry packaged foods is being developed. Here, we are going to present the results obtained in the Signal Processing Group (GTS) laboratories of the Universidad Politecnica de Valencia (UPV). Automatic system description and results for on line factory detection are not covered in this work.

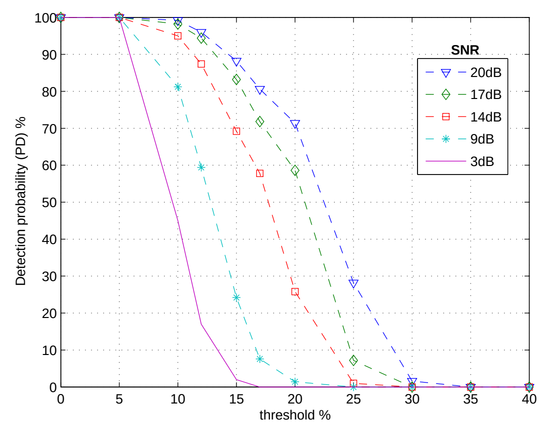

Figure 3: Detection probability graph for the proposed algorithm

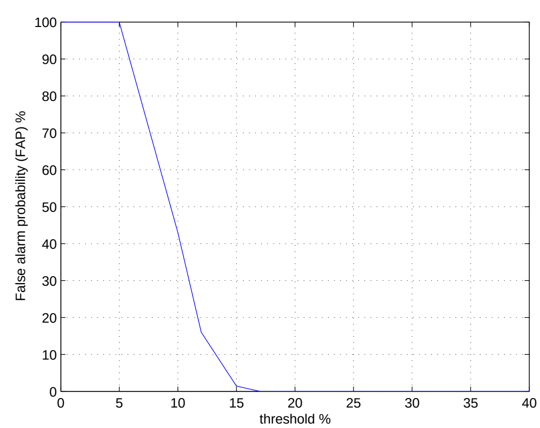

Figure 4: False alarm probability for the proposed algorithm

An ultrasonic PC board IPR-100 (Physical Acoustics) with 400 V of attack voltage and 46 dB in the receiver amplifier and damping impedance of 2000 Ohms was used. The transducer frequency was chosen to be 2.25MHz

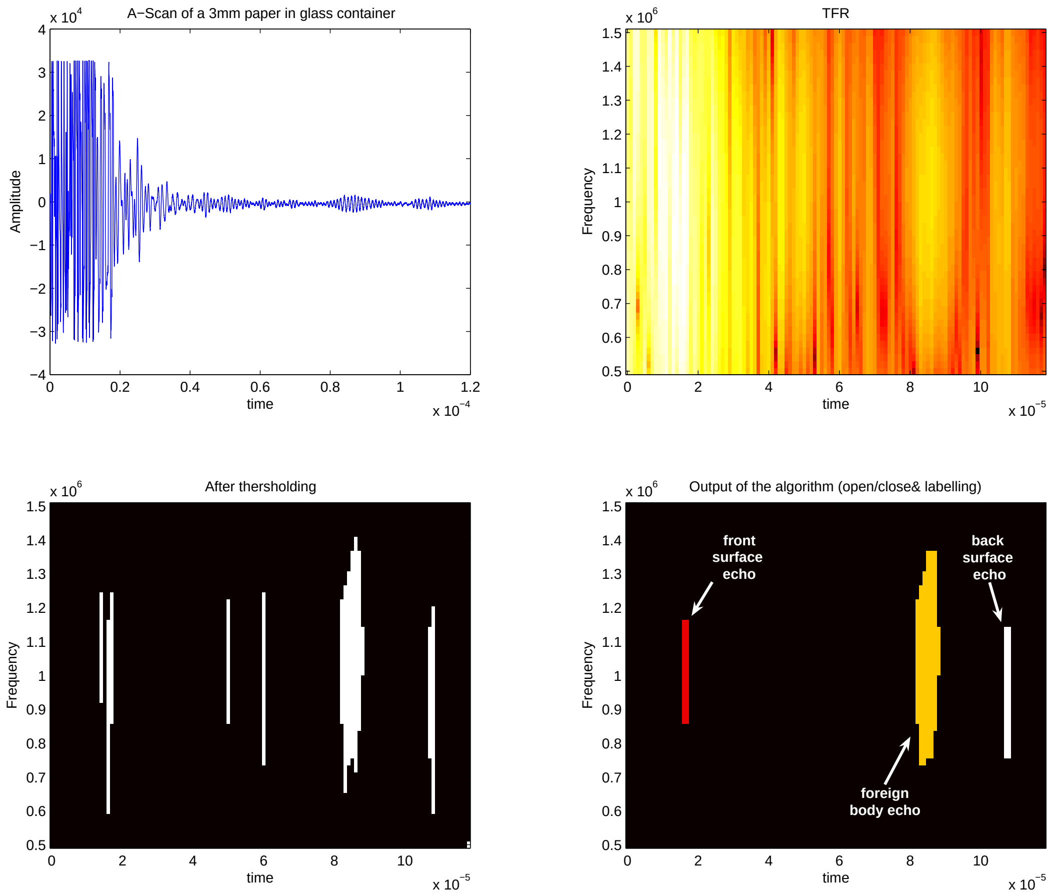

Figure 2: Graphical output at the different stages of the algorithm

(MSWQC52.25 transducer) for the artificially created laboratory phantoms and 1MHz (K1SC) for glass container experiments with artificially introduced foreign bodies. All the transducers probes employed from Krautkramer & Branson. Received signal was acquired with the Tektronix 3000 oscilloscope (f_s=50 MSamples/s).

Two different experiments to test the algorithm were designed. First we made meassures on phantoms similars to what is shown on the figure 5. The main idea was to have full control of all the variables introduced in our essays. We artificially introduced foreign bodies of different materials and sizes (see table 1). After acquisition, signals where processed using the proposed algorithm and results are shown on the previously mentioned table 1. The table shows good detection performance for foreign bodies larger than 3mm. Detection capability is strong related to acoustic impedance of the foreign body, due to this, there are some substances with similar acoustic impedance to the food alimentary product where is inserted that give worst detection results (rubber in this case). Unfortunately this transducer probe is of limited use for an industrial application, transducer element size is 6.3mm of diameter so we are inspecting a very small part of the container. We can either choose to use an electronic/mechanic scanning system or move to a lower frequency transducer with a higher element size. We have chosen this last option taking mainly into account the final price of the system.

The second experiment was a better approximation of how should work a final automatic inspection system. Figure 6 show meassures on glass containers. The transducer used has an element size of 28 mm (but it can be found on the market up to 34 mm of element size to allow higher inspection volume). The experiment gave good detection performance for papper, rubber and glass foreign bodies.

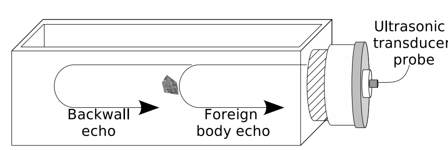

Figure 5: A real application to foreign bodies inspection artificially created laboratory phantoms (2.25 MHz)

	Detection at x cm away from transducer	
Foreign body	**x=4cm**	**x=6cm**
4mm glass	Yes	Yes
6mm glass	Yes	Yes
3mm metall	Yes	Yes
5mm plastic	Yes	Yes
2mm plastic	Yes	No
3mm paper	Yes	Yes
3mm rubber	Yes	No
7mm rubber	Yes	Yes

Table 1: Detection of different foreign bodies with the proposed algorithm for a 2.25 MHz MSWQC2.25 ultrasonic transducer probe

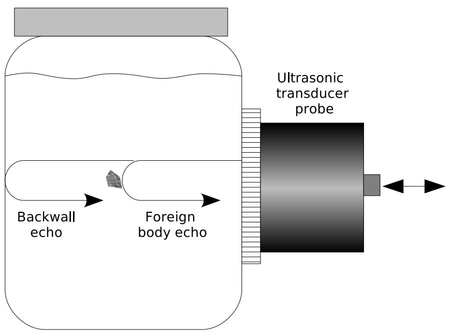

Figure 6: A real application to foreign bodies inspection on packaged sauce (1 MHz)

5. CONCLUSIONS AND FUTURE WORK

We have presented studies that show the viability of an automatic inspection system based on ultrasound energy for foreign bodies detection in the alimentary industry. Performance of the system strongly depend on the very specific acoustic impedance of the foreign body and the alimentary product we are working with. In case of sauces, detection up to 3 millimeter foreign body size has been done for glass, metall, plastic and paper.

Some future work that should be done:

- Study the possible effects that irregularities on the glass container will have on the final performance of the algorithm.
- Develop an automatization system for on line inspection.
- Work in how to avoid a blind zone due to multiple echoes on front surface of the container.

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