PERCEPTION AND ENTROPY INSPIRED ULTRASONIC GRAIN NOISE SUPPRESSION, USING NONCOHERENT DETECTOR STATISTICS

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Abstract

A novel approach for suppression of grain noise in ultrasonic signals, based on noncoherent detector statistics and signal entropy, is presented. The performance of the technique is demonstrated using ultrasonic B-scans from samples with coarse material structure.

1 Introduction

The main goal of ultrasonic grain noise suppression in material flaw detection is to improve the perceptual possibilities of the operator to observe defect echoes. The suppression is defined as *perceptually ideal* when a received signal (or image) which contains echoes buried in noise is filtered to yield nonzero values only at the positions of the defect echoes.

In statistical terms, a perceptual improvement is therefore obtained if the amplitude distribution in the filtered signal (image) is more concentrated around zero than in the raw data (contrast enhancement). A more concentrated amplitude distribution generally means smaller entropy. Thus, from an operator perception point of view, interesting results should be obtained if the raw data can be filtered to yield low entropy amplitude distributions. However, one should note that the entropy can be minimized by means of a (pathological) filter which always outputs zero or another constant value. Thus, appropriate restrictions must be imposed on the filter construction process.

Filters that output noncoherent detector statistics have, in our recent work [1], shown to be very powerful for grain noise suppression in ultrasonics. However, such filters require the operator to carefully specify a transient prototype as a model of the defect echoes which should be detected. Here a new approach is presented, based on the above ideas about perception, which eliminates the need for the operator to manually specify a defect prototype.

Experimental results on real ultrasonic B-scan data, acquired from samples with coarse material structure, are presented to demonstrate the power of the novel approach.

2 Noncoherent Detection and Family Detection

The noncoherent detector is well known from telecommnication, it is designed for detection of a band pass signal $s(t) = A(t)cos(2\pi f_o t + \phi)$ when the phase angle ϕ is unknown (random). From a NDT perspective, the noncoherent detector is designed to detect a family of transients defined by the set of transients obtained by continuously varying the angle ϕ over the interval $[0, 2\pi)$. Since it is impossible to exactly specify what transients to expect after propagation and reflection in NDT, the design of *family detectors* seems attractive.

For *clutter suppression*, the test statistic used by the noncoherent detector has been proposed as an interesting output signal [1]. This was motivated by the fact that, provided that transient and noise models are valid, the test statistic reflects the likelihood that a transient is present.

A very simple but useful transient model is

$$s(t) = e^{-at^2} cos(bt + \phi) \tag{1}$$

where a and b are two parameters which define the transient family to be detected.

In the work presented here, a slightly different two-parameter transient model has been used. Instead of specifying a center frequency b and the bandwidth parameter a of the amplitude function $A(t) = e^{-at^2}$, a simple band pass signal with lower and upper cut off frequencies f_{low} and f_{up} was employed. This implicitly defined a center frequency f_o and amplitude function $A(t)$. An example of a transient prototype both in the time and frequency domain is found in Figure 1.

In practice, it is nontrivial to manually select the parameter values to obtain successful results. Moreover, it is not obvious how to measure the quality of the results. Therefore, a well defined performance measure and an efficient parameter optimization method are desired.

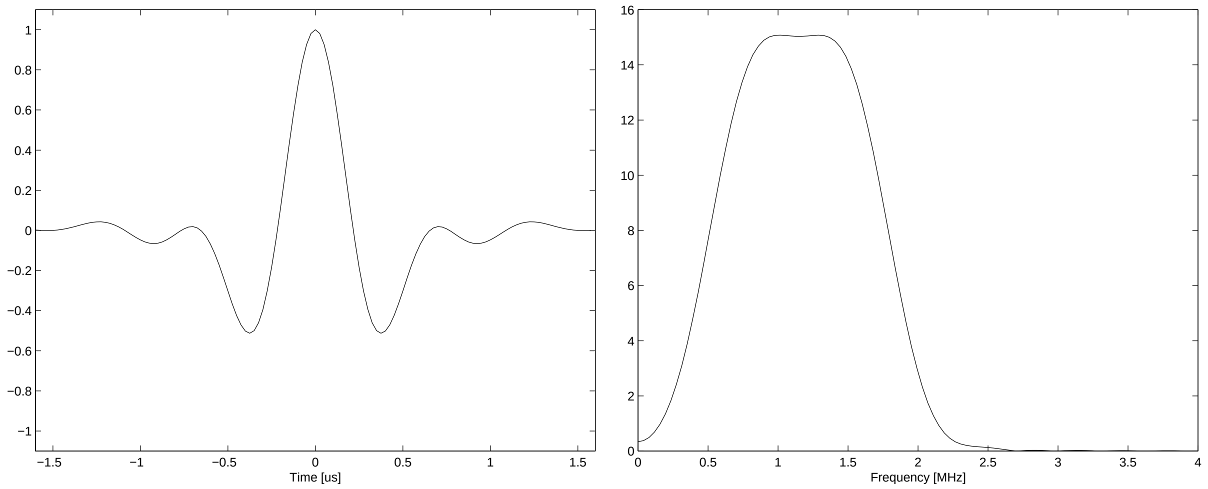

Figure 1: *Example of signal prototype in the time and frequency domains.*

3 Amplitude Entropy - A Performance Measure

One approach to a mathematically well defined performance measure is to interpret the amplitude values of a processed signal as realizations of a stochastic variable x which can take a discrete number of values x_n with probabilities $P_n, n = 1, 2, \ldots, N$. Briefly motivated in the introduction, then an interesting quality measure is the entropy $H(x)$ of the amplitude distribution defined as

$$H(x) = -\sum_{n=1}^{N} P_n ln(P_n) \tag{2}$$

In the experiments, the probabilities P_n were estimated from the processed signal by means of a histogram. It is well known that the entropy is large for nearly uniform distributions and small for distributions with few peaks. Thus it is an interesting candidate as a performance measure when the goal is to process a signal to become more easily interpreted.

4 Parameter Optimization

By means of the performance measure $H(x)$ described above, systematic and iterative search for good parameter values can be performed. In this work, one systematic and two iterative search methods were explored.

In the systematic approach, the contaminated signal was processed using transients with parameters selected from a uniformly sampled grid in the parameter space. For each parameter value, the quality of the processed signal was computed. An example result is presented in Figure 2 which shows the performance as a function of the two parameters f_{low} and f_{up}. The parameter values f^*_{low} and f^*_{up} which yielded the lowest entropy were selected for processing.

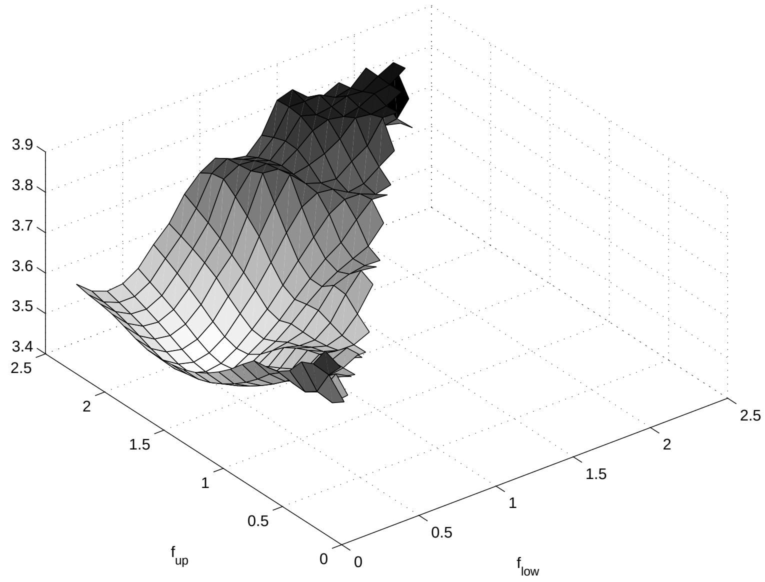

Figure 2: *A part of the entropy surface — a function of* f_{low} *and* f_{up}.

The advantage of such an exhaustive search is that the global minimum (within the resolution chosen) always can be found. However, exhaustive search is very time consuming. Therefore, steepest descent (gradient) optimization and genetic algorithms were also tested on the search problem. In summary, the gradient approach did not work well, it usually got stuck in local minima. However, genetic algorithms turned out to yield near optimal solutions within reasonable processing time.

5 Experimental Setup

The technique presented above has been extensively evaluated experimentally using ultrasonic data acquired from a test block made of cast stainless steel with coarse material structure. Here we briefly present selected results obtained using two pressure wave transducers, with refraction angles of 45° and 0°. The -10dB frequency ranges of the transducers were 1.4-2.8 MHz and 0.7-1.4 MHz, respectively. The ultrasonic response signals were sampled at a rate of 40 MHz, with a resolution of 8 bits, prior to computer processing.

6 Results

The 45° transducer was used to inspect side drilled holes, with their centres located 40 mm below the surface. Due to the coarse material structure the echoes from the holes were totally masked by clutter. An example of an ultrasonic response signal, emanating from a hole with a diameter of 8 mm, is shown in the left part of Figure 3. Scanning the surface above the 8 mm and 10 mm holes resulted in the B-scan image shown in the upper part of Figure 4.

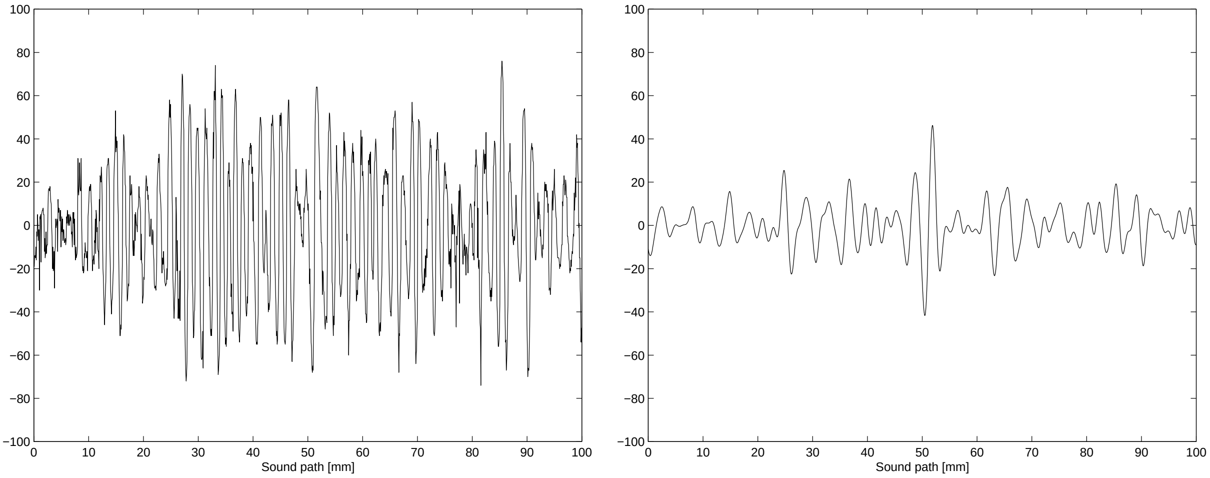

Figure 3: *Echo from 8 mm side-drilled hole at sound path 50 mm, before and after signal processing.*

The B-scan image was then processed according to the technique introduced above. Systematic sampling of the relevant prototype parameter space resulted in the entropy surface shown in Figure 2. The lowest entropy was obtained for a transient prototype characterized by $f^*_{low} = 0.5$ MHz and $f^*_{up} = 1.8$ MHz. This optimal prototype, see Figure 1, was then employed for noncoherent detection. The results are shown in the right part of Figure 3 and the lower part of Figure 4. Evidently, the clutter has been strongly suppressed and the side-drilled holes can be easily detected.

The same procedure was utilized for processing the B-scan image shown in the upper part of Figure 5. It was acquired by the 0° transducer, with the intention to detect the back wall echo through 300 mm of steel. In this case, the lowest entropy was obtained for a transient prototype characterized by $f^*_{low} = 0.2$ MHz and $f^*_{up} = 0.3$ MHz. The result of the subsequent processing of the image is shown in the lower part of Figure 5. The back wall echo, which originally was totally masked by clutter, is now clearly visible.

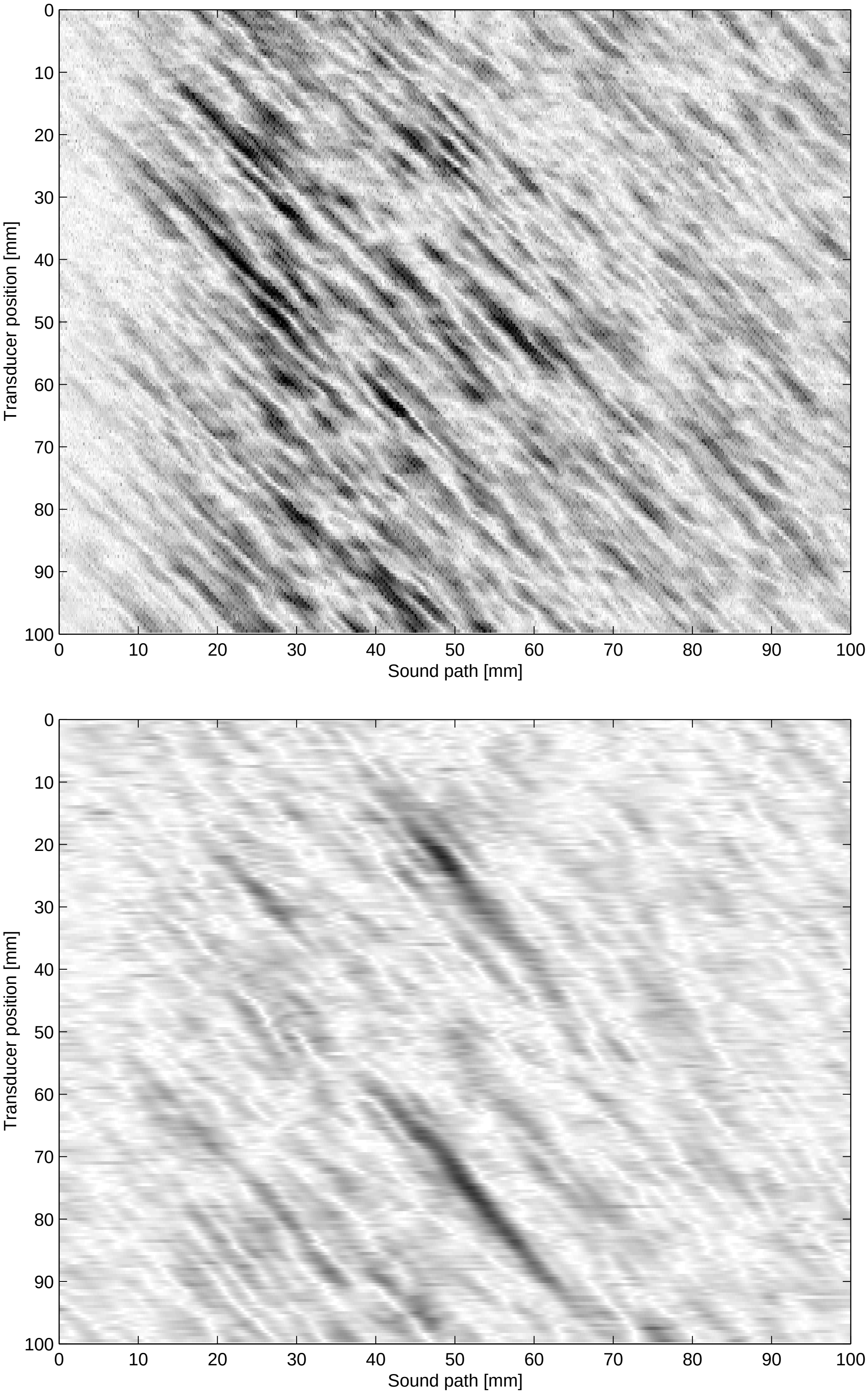

Figure 4: *Two side-drilled holes at sound path 50 mm, before and after signal processing. The 10 mm hole is located at transducer position 25 mm and the 8 mm hole at 75 mm.*

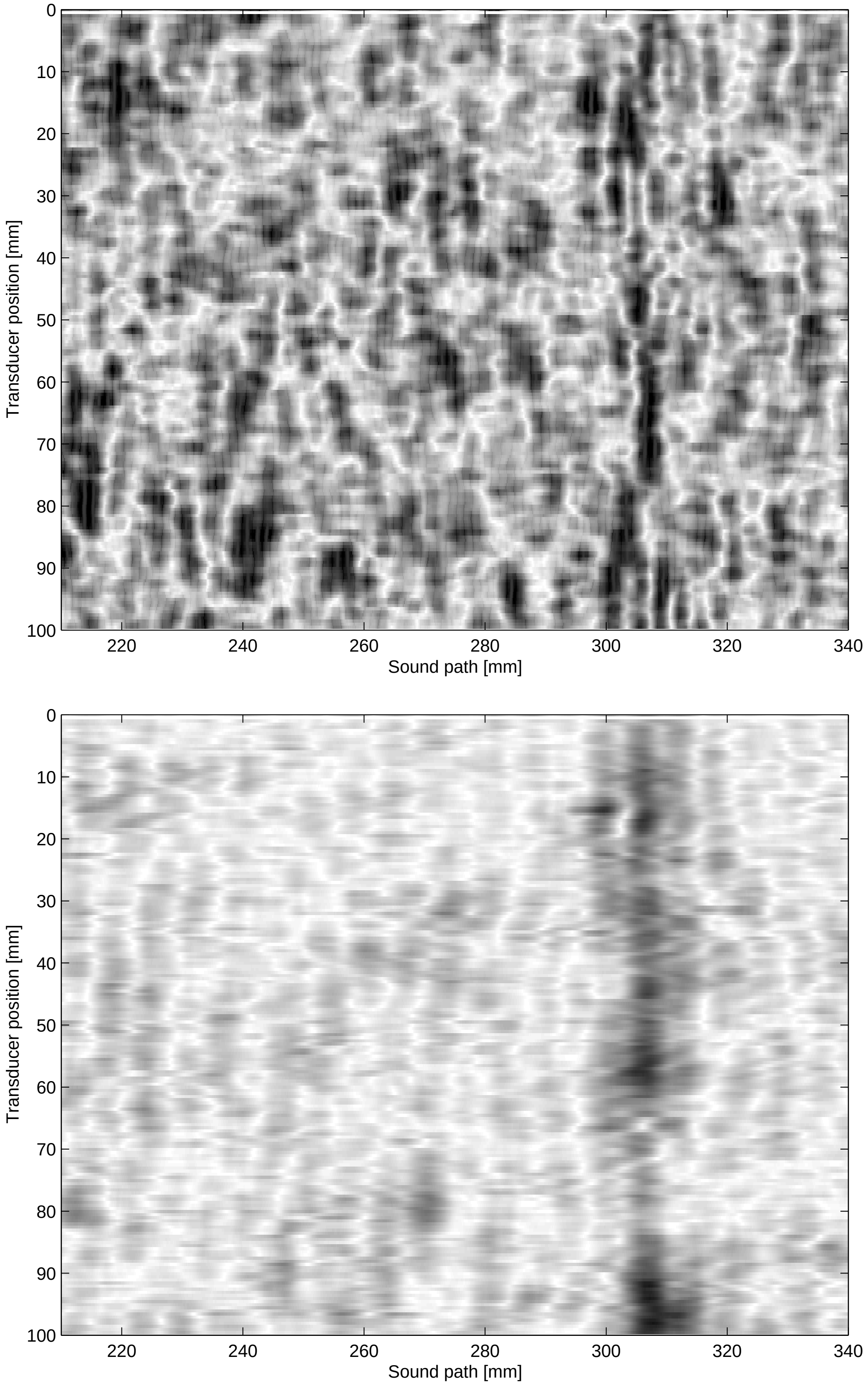

Figure 5: *Back wall echo through 300 mm of material, before and after signal processing.*

7 Summary and Future Developments

A novel approach for suppression of material noise in ultrasonic signals, based on noncoherent detector statistics and signal entropy, has been presented. Experimental evaluation of the technique, using ultrasonic images from samples with coarse material structure, has proven its high performance.

By employing this technique, the frequency range best suited for a particular material can be automatically estimated and utilized for inspection, without the need to employ a tailor-made transducer. Consequently, a single wide-band transducer can be used to get near-optimal inspection results for a wide range of materials.

In the near future the technique will be further evaluated using ultrasonic signals from natural defects, e.g., fatigue cracks. The performance measure and the parameter optimization procedure will also be refined in order to obtain a computationally efficient implementation, easy to use for a trained operator.

Acknowledgements

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References

[1] M.G. Gustafsson. Clutter suppression using noncoherent detector statistics. *Submitted to IEEE Transactions on UFFC*, 1997.