AN INDUSTRIAL APPLICATION OF SIGNAL PROCESSING: CERAMIC MICROCRACK DETECTION

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ABSTRACT

On line quality control in industrial plants is an open field for signal processing applications. In this paper we present a real-time prototype for the detection of microcracks in tiles of wet ceramic by means of ultrasonics. We also describe the signal processing algorithm applied and particularly how the false alarm probability (*PFA*) may be controlled. Finally an experimental test shows the agreement between the predicted *PFA* and the measured one, thus giving practical applicability to the proposed method.

1. INTRODUCTION

A quite common problem in ceramic and earthenware industry during the manufacture of tiles is the appearance of microscopic surface cracks in the raw ceramic clay. These fissures are only visible after the pieces bake into the kiln. Unfortunately then is too late: the crack broadens and finally breaks the tile making it useless. Moreover, this is the last step in the process. One possible solution is the use of ultrasonic pulse-echo techniques. These techniques are non-destructive and quite affordable. Nevertheless some problems arise:

- High attenuating materials, which produces low-level echoes.
- The vibration of the material as it passes through the travelling line.

In order to solve these problems, it is necessary the use of digital signal processing to distinguish the crack echoes from other ones. In this paper we present a complete portable real time-prototype for microcracks detection on ceramics materials. The developed prototype makes the ultrasonic measurements, the digitalization and the necessary digital signal processing, indicating if a crack exits or not.

The prototype is a portable personal computer with three expansion boards: one for the emission and reception of ultrasonic waves, another one for the digitalization of signals and the last one for the digital signal processing (DSP). The software running on the computer carry out the control of the three cards. The DSP card executes another program that implements the digital signal processing algorithms and the detector.

2. PROTOTYPE DESCRIPTION

The prototype consists of a hardware part and a software part. A functional scheme of the prototype is showed in figure 1.

2.1 Prototype hardware

The hardware of the prototype is composed of a portable personal computer placed over an expansion box that has three PC standard boards installed: an ultrasonic pulse/receiver board (Physical Acoustic Corporation IPR-90), an analog to digital converter board (Sofratest SFT4100), and a digital signal processor board (Ariel PC-32C with AT&T DSP32C). Additionally we utilize an ultrasonic transducer from Krautkrämer GmbH & Co model MSW-QC5 with center frequency of 5 MHz. In order to increase the distance between the transducer and the piece to avoid the pulse and echo overlap, the transducer is placed over a plastic 70º wedge as is showed in figure 1.

Microcracks use to appear on the edges of the tile, so the transducer must be placed on the tile, close and parallel to the edge under test, and has to be displaced in this direction all along the piece (figure 1).

2.2 Prototype software

The software of the prototype is composed of a monitor program running over the personal computer that configures and controls the three boards, and a slave signal processing program running over the DSP card.

The final objective of this system is to determine in real time if the tested tile is cracked or not. We can divide the process in two steps, the measurement acquisition phase and the detection phase. The former includes the UPR, ADC configuration and control, whereas the latter includes the measurement processing and the decision about the result.

The digital signal processing algorithm also has two differentiated parts: calibration and processing. During calibration it is necessary to do some measures that permits the adjustment of some parameters of the detector that we will need in the processing phase to have a control of the *PFA*. The adjustment has to be made only once per type of material. This calibration is realized over pieces without cracks, thus we can adjust the parameters of the algorithm [1] in order to obtain the desired probability of false alarm.

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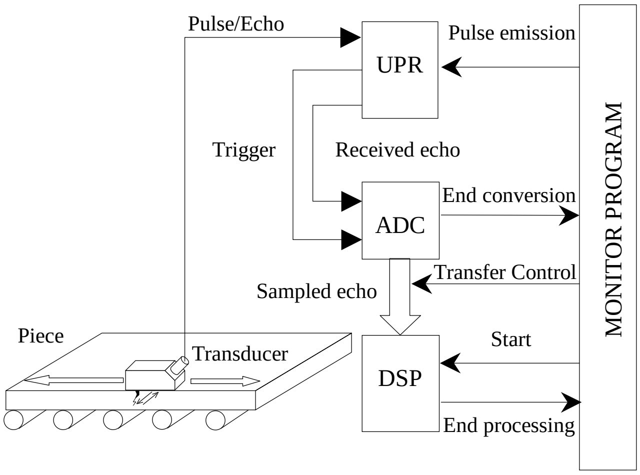

Figure 1. Scheme of the prototype.

3. DIGITAL SIGNAL PROCESSING ALGORITHM

3.1 Noise model

The first thing that we need in order to design a *PFA* controlled detector is the noise distribution.

For the grain noise we are going to use a statistical model. In particular the ultrasonic grain noise can be considered to be *K*-noise, which is a type of parametric non-Gaussian noise proposed by Jakeman [2, 3] for modelling the sea clutter in radar applications and more recently used in ultrasonic non destructive testing [4, 5]. The *K*-noise has a *K*-distributed envelope, having a probability density function (PDF) of the form:

$$p_e(e) = \frac{2b_e}{\Gamma(m_e)}\left(\frac{b_e e}{2}\right)^{m_e} K_{m_e-1}(b_e e)$$

(Eq. 1)

Where b_e, m_e are the parameters of the distribution (being m_e greater than 0) and K_{m_e-1} is the (m_e-1)-th order modified Bessel function of third kind. On the other hand, we will consider, as usually, that the phase is uniformly distributed between 0 and 2π.

Changing the parameter m_e (the parameter b_e is just a scale factor equal to $2\sqrt{m_e}$ when the noise is unit power normalised) in the *K*-distribution we may consider a wide family of PDFs, ranging from a log-normal distribution for m_e values close to 0, to a Rayleigh distribution (Gaussian in-phase and quadrature components) for m_e greater than 10. Thus the impulsive character of the *K*-noise increases as the parameter m_e approaches to zero.

3.2 Algorithm

The algorithm implemented in our prototype was presented in [6] and the necessary steps for automatic detection and *PFA* adjustment are shown schematically in the figure 2.

Graphically the algorithm is described in the figure 2. First the Wigner-Ville Transform (WVT) is computed and binarized by means of a threshold (T). Then the "binarized" WVT ("0" if lower than T, "1" if upper than T) is summed around the central frequencies and the final decision (crack or not crack) is made by means of a double threshold T_f , T_t. A detection is made when the number of 1's in a given time of the binarized WVT is greater than T_f during T_t consecutive instants.

The expression of the $PFA_{isolated}$ was obtained in [6] :

$$PFA_{isolated}(T) = P_+ \frac{2}{\Gamma(m_+)}\left(\frac{b_+ \cdot T}{2}\right)^{m_+} K_{m_+}(b_+ \cdot T)$$

(Eq. 2)

Where P_+ is the percentage of positive values of the noise WVT, m_+, b_+ are parameters derived from the *K*-noise parameters (m_e, b_e) and T is the threshold previously defined. The expression of the complete *PFA* was also derived in [6] and is given by:

$$PFA_{complete}(T_f, T_t) \approx \left(\sum_{k=T_f}^{N} \frac{N!}{(N-k)!\,k!} PFA_{isolated}^{k} (1 - PFA_{isolated}^{k})^{N-k}\right)^{T_t}$$

(Eq. 3)

Where N is the number of frequency lines considered in the selected band of the WVT.

From (Eq. 2) and (Eq. 3) we can determine the theoretical or predicted $PFA_{complete}$ for any selected set of values T, T_f and T_t .

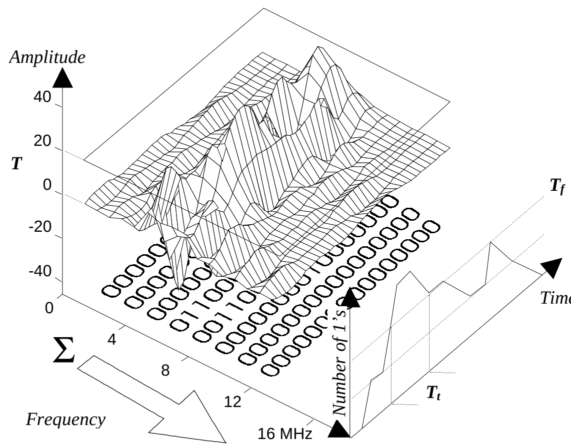

Figure 2. Binarization and double threshold applied to the WVT

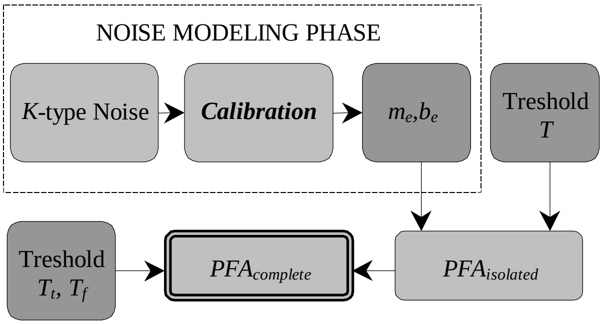

Figure 3. *PFA* control scheme.

4. EXPERIMENTAL TEST

We now present the results from applying the proposed detector to real ultrasonic echo data. The study tries to validate our model in what *PFA* is concerned.

The specimens employed in our experiment were non-burned non-cracked clay tiles of $330\times330\times7$ mm. Medium density gel was placed in the interface between the transducer and the clay. The ultrasonic echo was sampled at 50 MHz with 8 bits giving records of 1000 samples length. In total 400 records were obtained from different parts of the specimen.

The experiment was made on the laboratory, free of undesirable interfering vibrations.

4.1 *PFA* for isolated points

First of all we are going to present the comparison between the real $PFA_{isolated}$ and the theoretical $PFA_{isolated}$. This intermediary *PFA* is needed to calculate the *PFA* of the complete detector (figure 3).

To show the relationship between the theoretical $PFA_{isolated}$ (Eq. 2) and the estimated $PFA_{isolated}$ from ceramics, we have calculated the WVT of each of the ultrasonic signals. The WVT has been calculated using the Boashash and Black algorithm [7], with 15 points windows and 16 lines of spectral resolution. The *K*-noise parameter has been estimated by means of the Raghavan test [8, 9].

The average $PFA_{isolated}$ estimation has been plotted in the figure 4, together with the theoretic results from (Eq. 2) where the signals have been unit power normalized. As it can be seen, the estimations fit quite well the theoretic values. Note that the binarized WVT could be the input to a human observer to decide if there is a crack or not. If a complete automatic detection is desired then we should use the complete test.

4.2 *PFA* for the complete test

In this section we present the results of the *PFA* for the complete detector and compare it to the theoretic results (Equation 3). This can be done following the process previously described (figure 2). Once we have "binarized" the WVT the three spectral lines number 10, 11, 12 of the WVT have been chosen for further processing. These spectral lines concentrate the maximum percentage of backscattered noise energy. The $PFA_{complete}$ has been estimated for T_f =3 and T_t =1 values. The result is plotted in the figure 5 where it has been also plotted the theoretic curve from Eq. 3 (solid line) for *N*=3.

As it can be seen from the Fig. 5 there is some deviation between the theoretic and the real curve. In any case the adjustement is good for very small *PFA* values. The practical application of the proposed detector to the microcrack ceramic problem requires negligible values for the $PFA_{complete}$ to avoid rejection of a non-cracked piece, when many measurements are to be made on the same piece. So the control of the *PFA* is in the sense of predicting which *T*, T_f and T_t set of values guarantees a negligible *PFA*, while maintaining good detection properties (*i.e.* *T*, T_f and T_t should be chosen as small as possible). Thus, figure 5 (dotted line) indicates that a value $T\approx2.5$ is enough to have a negligible *PFA*, being this conclusion in concordance with the theoretical predictions (solid line).

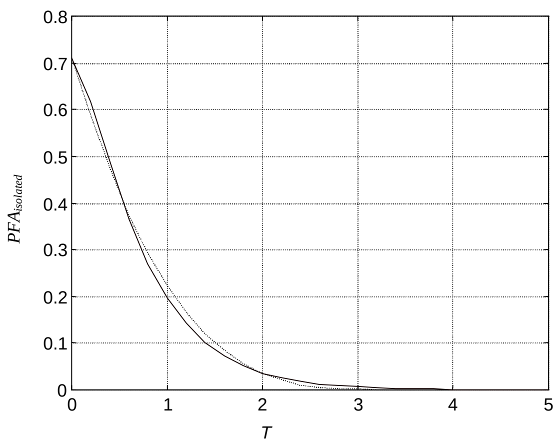

Figure 4. $PFA_{isolated}$ from Eq. 8 (solid line) and from ultrasonic measurements (dotted line).

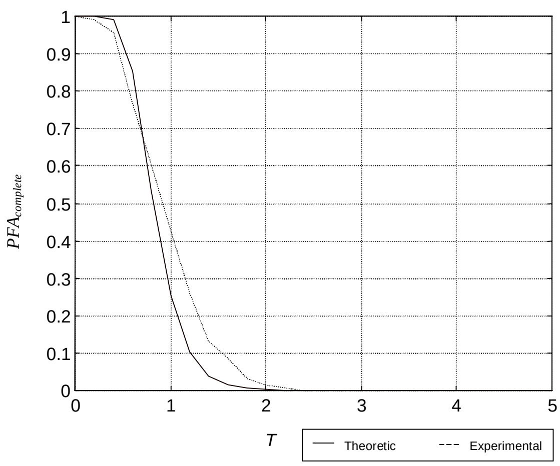

Figure 5. $PFA_{complete}$ for: T_f =3 T_t =1.

5. CONCLUSIONS

We have concluded the feasibility of detecting microcracks in ceramic tiles by combining ultrasonic technology with digital signal processing. A key point in this problem is to have a very small *PFA* value, while maintaining the capability of detection as large as possible. We have verified that by means of a previous and simple calibration process, the adequate threshold values to achieve that goal may be precisely estimated. A PC based prototype has been also presented for making the ultrasonic measurements.

6. REFERENCES

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