Pattern recognition based approach for extraction of factors of interest from ultrasonic data

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***Abstract* — Typically, ultrasonic testers use a single parameter, such as pulse velocity, to evaluate the condition of materials and biological tissues. In complex media like composite materials and biological tissues, the use of a single parameter is not sufficient to discriminate a few independent factors interest (FOI), such as the degree of deterioration, geometric parameters, and composition. For compact bone tissue in the respect of osteoporosis, FOI are cortical thickness and internal porosity. To estimate unknown values of FOI in an object under study, a pattern recognition approach was applied to the totality of ultrasonic signals obtained by scanning the object's surface. The signals formed spatiotemporal waveform profiles composed of different acoustic modes carrying information on FOI. The recognition method included creating a set of decision rules based on the data extracted from the ultrasonic data of objects with *a priori* known FOI and to estimate the FOI of a new object. The decision rules are both mathematical criteria of ultrasonic signals passed through the discrete Fourier transform and physical parameters of ultrasound propagation like the velocities of fast and slow acoustic modes.**

Keywords— pattern recognition, factors of interest, ultrasonic signals

I. INTRODUCTION

The task of determining the values of two simultaneously acting factors of interest (FOI) in the ultrasonic examination of real objects is actual in different fields of non-destructive testing and research. For example, in civil engineering, this is the determination of the state of concrete in the depth from the surface and the determination of bone porosity and thickness in medical diagnostics of osteoporosis. This work proposes a pattern recognition approach for the determination of FOI using a small number of objects as a knowledge base, where there is difficulty in creating a large number of test objects. This approach can be used in cases where the use of advanced methods of pattern recognition is difficult or impossible due to insufficient initial data. The approach was approbated in the study of ultrasonic manifestations of osteoporosis in compact bone. Pattern recognition approaches were applied to a totality of ultrasonic signals obtained by the axial scanning of synthetic bone phantoms, where FOI were the cortical thickness and intracortical porosity.

II. PROPOSED APPROACH

The evaluation method is based on the principles of pattern recognition and consists of two parts: creating a set of decision rules using the data for a training set of specimens and validating the set of decision rules by substitution the data for an examination specimen to make sure that the proposed approach is correct.

A. *Initial data and primary signal processing*

Initial data for extraction of factors of interest was a set of ultrasonic signals(t), obtained by stepwise ultrasonic surface scanning.

Each of the discrete signals $s(t)$ $(t \in [t\_min; t\_max])$ was converted by discrete Fourier transform (DFT) [1] into the spectral signals $M(\omega)$, $(\omega \in [\omega\_min; \omega\_max])$ describing the magnitude spectrum:

$$M(\omega) = \sqrt{\left(Re(\omega)\right)^2 + \left(Im(\omega)\right)^2}$$

where:

$$Re(\omega) = \sum_{t=t\_min}^{t\_max} s(t) \cdot cos\left(\frac{2\pi \cdot t \cdot \omega}{t_{max} - t\_min}\right)$$

and

$$Im(\omega) = \sum_{t=t\_min}^{t\_max} s(t) \cdot sin\left(\frac{2\pi \cdot t \cdot \omega}{t_{max} - t\_min}\right)$$

.

In further processing, the considered interval ω satisfied the following conditions: $M(\omega) \geq \varepsilon 1 \cdot max\{M(\omega)\}$ and $\omega \leq 0{,}5 \cdot (\omega\_max - \omega\_min)$.

The entire set of DFT signals was used to describe the object. In a selected interval ω, the values of three functions were calculated as $F\_max(\omega) = max\{M(\omega)\}$, $F_{avr(\omega)} = average\{M(\omega)\}$ and $F\_min(\omega) = min\{M(\omega)\}$. The next step was the calculation of mathematical criteria for each of the objects [2]. These mathematical criteria form a feature vector describing the object, where the values of the FOI of this object are *a priori* known. The novelty introduced in the present study related to the structure of the input data. The proposed approach used a non-orthogonal structure of the data grid, where FOI1 (cortical thickness) changed with a regular step, whereas the step for FOI2 (intracortical porosity) was proportional to FOI1.

B. *Decision rules*

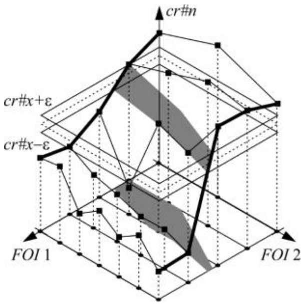

Fig. 1. An example of using a single decision rule to evaluate ranges of possible values of FOI1 and FOI2 in an unknown object.

The FOI estimation method was based on the creation and use of decision rules. To create decision rules for an irregular data grid, a piecewise linear interpolation was used for each of the parametric directions. As a result, the decision rule was represented as a piecewise bilinear function of two variables in each segment in the FOI space. The use of a decision rule to evaluate an unknown object was reduced to the calculation of mathematical criteria and their comparison with the corresponding decision rules. In this case, the value of the criterion expanded to the interval ±ε that could vary from 1 to 20% depending on the criterion and the evaluation tolerance. Fig.1 illustrates the result of evaluation according to one rule as a segment of possible correct answers.

In the model experiments, two subsets were formed from the set of available objects: a training set and a test set. The decision rules were formed using only the training set. At the same time, there was no such pair of objects (one from the training set and the other from the test set) with the same FOI values. Thus, the proposed approach was not transformed into a classification problem but used an estimate of intermediate FOI values between objects from the training set.

At each segment, the number of intersections of the set of statistical criteria with the corresponding decision rules was computed as

$$sum = \sum_i s\_cr[i]$$

The segment, where the number of the intersections was maximal, gave the final estimate of FOI for the test specimen. Fig.2 illustrates the case of three decision rules. The common segment contained a part of all individual segments obtained by the intersection of the decision rules and was the final estimate of FOI ranges. Numerical values of FOI can be estimated as the center of mass of the common segment.

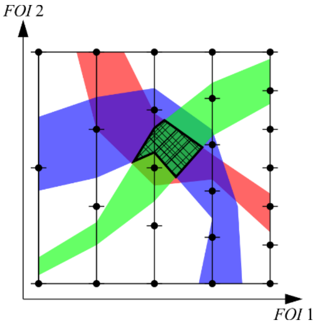

Fig. 2. An example of the intersection of 3 decision rules allowing to specify and narrow ranges of possible values of FOI1 and FOI2.

III. EXPERIMENT

Experimental validation of the proposed approach to demonstrate its effectiveness in the determination of FOI was done using a series of phantoms simulating signs of osteoporosis in compact bone tissue. The phantoms (objects) were 25 acrylic plates with gradually changing total thickness in the range of 2-6 mm in increments of 1 mm (FOI 1) and the progressing of intracortical porosity from the bottom layer also in increments of 1 mm (FOI 2). The data grid FOI 1- FOI 2 was an irregular one that foresaw the piecewise linear interpolation. In each object, 24 ultrasound propagation signals from the emitter to the receiver at 100 kHz were collected at the gradually changing acoustic base from 20 to 89 mm in increments of 3 mm. The totality of ultrasonic signals formed so called spatiotemporal waveform profiles (Fig.3), which contained complex information on the temporal and power features of different acoustic modes in the object. Ultrasonic signals were processed by DFT with the further calculation of the decision rules.

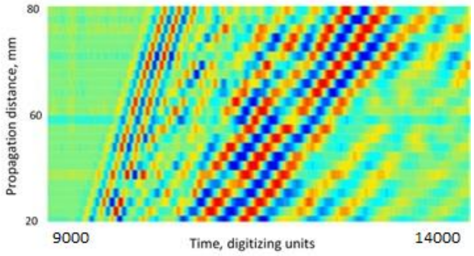

Fig. 3. An example of spatiotemporal waveform profile formed by ultrasonic signals at a gradually changing acoustic base.

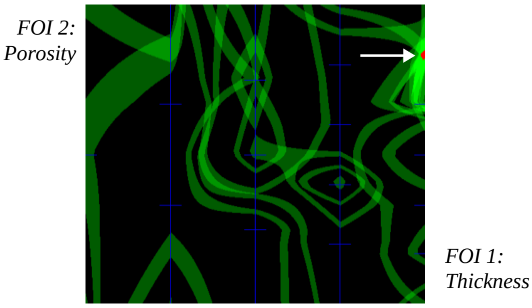

Fig. 4. An evaluation example of an unknown object: arrow and red square show the real position of the test object in the field FOI 1- FOI 2. The detection result corresponds to the brightest area of the intersection of decision rules.

Fig.4. illustrates an example of the detection. In this example, despite the presence of multiple individual intersections, the final answer corresponding to the maximum of intersections matches the *a priori* known FOI1 and FOI2.

IV. CONCLUSIONS

The scope of the proposed approach is the solution of detection tasks with a small number of available objects, in which the use of artificial intelligence methods (for example - neural networks) is difficult or impossible.

The experimental results obtained on ultrasonic signals in osteoporosis bone phantoms showed the effectiveness of the proposed assessment method. However, to improve the accuracy of the assessment of factors of interests (FOI), it is necessary to include not only mathematical criteria based on DFT of ultrasonic signals but also physical parameters of ultrasound propagation in time and frequency domains (that is the subject of further research).

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REFERENCES

[1] Stone J.V. (2021) The Fourier Transform: A Tutorial Introduction, Sebtel Press, Annotated edition, 103 p.

[2] Sisojevs A., Tatarinov A., Kovalovs M., Krutikova O., Chaplinska A. An approach for parameters evaluation in layered structural materials based on DFT analysis of ultrasonic signal. Proceedings of the 11th International Conference on Pattern Recognition Applications and Methods, 2022. - Volume 1: ICPRAM, 307-314