GENETIC FEATURE SELECTION AND STATISTICAL CLASSIFICATION OF VOIDS IN CONCRETE STRUCTURE

G. Acciani, G. Fornarelli, D. Magarielli and D. Maiullari
Departement of Electrical and Electronical Engineering, Politecnico di Bari, Via E. Orabona 4, 70125 Bari, Italy

Keywords: Ultrasonic waveforms, Non-Destructive Techniques, Concrete Structure, Genetic algorithms, *k*-NN.

Abstract: In this work simulated ultrasonic waveforms in a concrete specimen obtained by a software based on finite element method were used to develop an automatic inspection method. A piezoelectric transducer is used to generate stress waves that are reflected by voids. Then the waves are received by another transducer set at a fixed distance from the first one on the same specimen surface. Time and frequency features has been extracted from the waveforms, the most significant features have been chosen by a genetic feature selection and the classification performances were estimated referring to a *k*-NN classifier.

1 INTRODUCTION

Concrete structures like bridges, tunnels, walls or infrastructures require periodic inspections and quality control to assess their structural integrity. In order to track and evaluate the symptoms of deterioration or damage that may compromise service quality or safety, many advanced Non-Destructive- Techniques (NDT) have been developed and applied (Berriman, 2006).

During the last years, the methods based on the propagation of ultrasonic waveform have attracted researcher's interests due to their effectiveness in the localization of structural components and internal defects like cracks or voids, particularly the pulse-echo method is a common, simple and suitable approach for field operation test. By driving a dynamic force via a piezo-electric element, elastic waves are generated and propagated in concrete where the stress waves are scattered, reflected, attenuated and resonated. A receiver is used to detect the arrival of reflected waves (echoes), so that the time of flight (round–trip travel period) of these waves can be calculated. Wave reflections are produced by internal defects, interfaces between materials with different densities and elastic properties and boundaries of the solid. This method is used to determine the location of defects or interfaces by knowing the velocity of stress waves and measuring their time of flight (Fan, 2006). Many methods was developed in which the evaluation of the travel time of ultrasonic signal echoes is focalized on defects of large extension (delamination or cracks). In this paper an automatic inspection method based on a genetic algorithm and a statistical approach is proposed. In this method the travel time estimation is avoided and the localization of defects with small dimensions is carried out.

In the field of the automatic classification of defects the greater problems to be solved are how to extract significant flaw information and how to interpret this kind of information. In this work, it has been referred to 71 time and frequency features characterising ultrasonic waveforms used for the non-destructive defect detection in not accessible pipes (Acciani, 2006). The significant flaw information is then obtained by the feature selection which is committed to a genetic approach, based on the *k*-Nearest Neighbor (*k*-NN) classifier.

2 ULTRASONIC PROPAGATION

In this work the considered test is an homogeneous isotropic concrete specimen whose geometric and physical properties are summarized in Table 1.

On a free surface of the test specimen, a transducer consisting of a piezoelectric thin layer generates the stress waves which are detected from a receiver situated on the same side of the emitter (indirect transmission).

Acciani G., Fornarelli G., Magarielli D. and Maiullari D. (2008).
GENETIC FEATURE SELECTION AND STATISTICAL CLASSIFICATION OF VOIDS IN CONCRETE STRUCTURE.
In *Proceedings of the Tenth International Conference on Enterprise Information Systems - AIDSS*, pages 231-234
DOI: 10.5220/0001692802310234

Table 1: Geometric and physical characteristics of concrete specimen.

Quantity	Value
Width (x_2)	1.0 m
Depth (x_3)	0.3 m
Height (x_1)	1.0 m
Young's Modulus	$E=25\times10^9$ Pa
Density	$\rho=2300$ kg/m^3
Poisson's ratio	$\nu=0.33$
First Lamé constant	$\mu=9.398496\times10^9$ Pa
Second Lamé constant	$\lambda=1.824414\times10^{10}$ Pa
Velocity of longitudinal wave	v_P= 4013.08 m/s
Velocity of transversal wave	v_S= 2021.46 m/s
Velocity of surface wave	v_R= 1884.00 m/s

The piezoelectric layers are Piezo Zirconate Titanate (PZT 27) commonly employed in ultrasonic techniques whose diameter is D=0.05 m, piezoelectric constant $d=425\times10^{-12}$ m/V, strain-voltage constant $h=1{,}46\times10^9$ V/m. The excitation voltage applied to the piezoelectric layer is an Hamming windowed sinusoid, with a duration of three periods, whose analytical expression is given by the following equation:

$$V_e(t)=V_M\cdot\left[\frac{1}{2}\left(1-cos\left(2\pi\frac{f}{3}t\right)\right)\cdot sin(2\pi ft)\right]\cdot\left(t\le\frac{3}{f}\right)\ [V] \qquad (1)$$

where f is the central frequency excitation and V_M is the amplitude of the sinusoid. The ultrasonic waves propagation has been analyzed on the plane containing the transducer axis as shown in figure 1.

The propagation in the specimen under test in absence of body forces can be written as follows (Rose, 1999):

$$\rho\frac{\partial^2\mathbf{u}}{\partial t^2}=(\lambda+\mu)\nabla(\nabla\cdot\mathbf{u})+\mu\nabla^2\mathbf{u} \qquad (2)$$

where $\mathbf{u}=[u_1\quad u_2\quad u_3]^T$ is the displacement field.

Moreover, appropriate boundary conditions must be added to these equations. At free surfaces it is requested that the traction vector vanish, thus boundary conditions are:

$$\boldsymbol{\sigma}\cdot\mathbf{n}=\mathbf{0} \qquad (3)$$

where $\boldsymbol{\sigma}$ is the stress tensor and $\mathbf{n}=[n_1\quad n_2\quad n_3]^T$ is the outward unit normal to the boundary.

On each point of the contact surface between the specimen and the emitter the displacement values have been imposed by the equation:

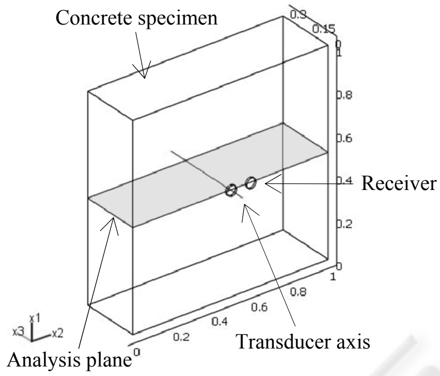

Figure 1: Simulation.of Set-up.

$$u_3=d\cdot V_e(t) \qquad (4)$$

The displacements on the contact surface between the specimen and the receiver are proportional with the voltage across the piezoelectric transducer through the strain-voltage constant h:

$$V_r(t)=h\cdot u_3(t) \qquad (5)$$

The software used to simulate the considered case is Comsol 3.3, a commercial code based on the Finite Element Method (FEM). The considered simulation have been carried out considering an excitation frequency f=70 kHz, an analysis time $T=4\times10^{-4}$ s, a quad mapped mesh with dimension sides m=0.6 cm. Such value of m corresponds to 1/10 of the central frequency wavelength, in order to guarantee the numerical accuracy provided by the solution algorithm.

In figure 2 a) the qualitative progress of the wavefronts for the specimen previously considered with two square voids (side dimensions 2 cm) are depicted. Particularly, the radiation field at 78% is pointed out by the oblique lines. It means that the displacement amplitude of a point of fixed wavefront reduces to the 78% compared with the displacement amplitude of a point belonging to the same wavefront and aligned with the transducer axis. The two considered defects are placed on the center of the radiation field and on the same wavefront on the border of the radiation field.

Figures 2 b) and 2 c) represent u_3 displacement waveforms evaluated on the same position of the emitter for the central and not central defect, respectively. It is possible to note that in the second case the echo amplitude due to the defect could be undetectable in the presence of noise.

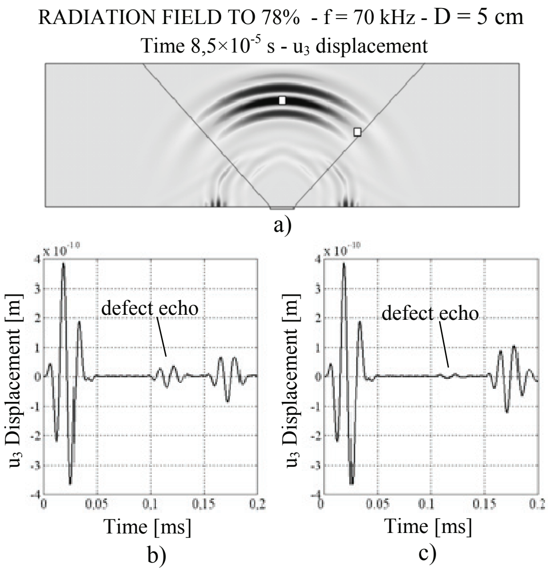

Figure 2: Comparison between u_3 displacements: a) defects position; b)waveform for defect aligned with transducer axis; c) waveform for defect aligned with the radiation field border.

For these reason the defects considered in the present work are placed all in the radiation field previously defined.

3 DIAGNOSIS APPROACH

In this section the proposed approach to classify the defects on concrete structures is discussed.

A set of 71 parameters characterising ultrasonic waveforms have been extracted from the simulated waveforms. The most significant features have been chosen by a genetic feature selection (Muni, 2006).

GA are a class of robust problem-solving techniques based on a population of possible solutions, which evolve through successive iterations by means of the application of three genetic operators: selection, crossover and mutation.

A solution is represented by a finite sequence of 0's and 1's called chromosome. For the problem of feature selection, a chromosome has length *d* that corresponds to the total number of features. A '0' represents a rejected feature, whereas a '1' stands for a selected feature.

To start the solution process, the GA has to be provided with an initial population. The most commonly used method is the random generation of initial solution for the population. Then the chromosomes are allowed to 'crossover': two chromosomes, generally selected with a random criterion, exchange their parts at a chosen point to create two new chromosomes. Chromosomes are also allowed to 'mutate': by flipping one or more bits can be made to a chromosome.

The optimization process is carried out in 'generations', each time a population of new chromosomes is generated, until some criterion is met. The most commonly used terminating criterion is the maximum number of generations.

Since the population size is finite, only the 'best' chromosomes are allowed to survive. The various generations experience the processes of crossover and mutation each of which happens with a certain probability. The mechanism of crossover interests a subset of the population that is identified by means of a criterion of 'selection', chosen from these available in literature. There is also a mechanism of replication (or 'elitism') according to which no change is made and a certain number of individuals is simply copied from the current generation to the next. The next generation is chosen from the new individuals created and from the previous generation according to a fitness function that allows to calculate a fitness score for each of the chromosomes. In the genetic feature selection, it is critical to design an appropriate fitness function to avoid local minima. Traditionally, in the GA-based feature selection problems, the fitness function used is simply a hit rate function. The fitness function considered in this paper takes into account the classification performance and the ratio between the used features and the number of all defined features. In particular, the classification performance has been estimated referring to *k*-NN classifier and the analytical expression of the considered fitness function is:

$$fitness = f(X_i) - \alpha \frac{|X_i|}{D} \tag{6}$$

where *f*(.) is the hit rate, $|X_i|$ is the number of selected features for the chromosome X_i, D is the number of all the measured features, α is a de-emphasis coefficient that has been fixed equal to 1/10. α coefficient sets the weight of the number of the features compared with the classification rate.

Some preliminary experiments were carried out to try out an optimal set of operators and parameters of the GA useful for the investigation considered in this work. With the experience gained from these explorations, the parameters have been set as shown in the Table 2.

Table 2: Description of genetic algorithm parameters.

GA parameters settings	Value or type
Initial population choice	Random
Population size	100
Number of generations	100
Selection criterion	Roulette wheel
Elitism (nr. of unchanged individuals)	10
Crossover (nr. of selected individuals)	50
Crossover rule	Single point crossover
Crossover probability	1
Mutation probability	0.02
Termination criterion	Maximum nr of generations

4 EXPERIMENTAL RESULTS AND DISCUSSION

In order to test the proposed localization method, a database of 90 simulated ultrasonic waveforms has been obtained adopting the specimen and the configuration analysis described in Section 2. In this test case, 10 classes of defects with different positions, inside the transducer radiation field, and 9 square voids (side 2 cm) for each class have been considered, as shown in figure 3. Finally, the collected signal set has been contaminated and augmented by additive white Gaussian noise considering four noisy waveforms for each signal of the database. The extended data set of 90×4=360 waveforms, has been randomly divided into training subset (90%) and test subset (10%) with the aim to examine the robustness of the automatic interpretation scheme. By according the above described method, the 71 time and frequency domain parameters for each waveform of the database have been evaluated. Then the genetic feature selection based on *k*-NN algorithm has been used to select the optimal feature set for voids position classification. The performances of *k*-NN have been evaluated in terms of Mean Classification Error (MCE), that is calculated as the mean of the errors in the classification of the test set waveforms. The better results have been obtained with the number of neighbours k = 3 for the *k*-NN. In this case, the MCE starts from a value of 38.89% in correspondence of the whole set of 71 features, but the GA-based feature reduction allows it to increase up to the value of 97.22% with a selection of only 7 significant features listed below: Difference between 50% level and 25% level (spectrum CD); Difference between 75% level and 25% level (spectrum CD); Difference between 90% level and 25% level (spectrum CD); Global rise frequency between 25% level and peak of spectrum; Global rise frequency between 50% level and peak of spectrum; Global fall frequency between peak of spectrum and 50% level; Global rise variance between 25% level and peak of spectrum (CD = cumulative distribution).

The results show that the adopted method provides a low error rate for the identification of position of voids. Therefore, it would be a contribute to develop an automatic method to localize defects by means of ultrasonic analysis in concrete structures. Future works will be devoted to a more accurate identification of the position of voids.

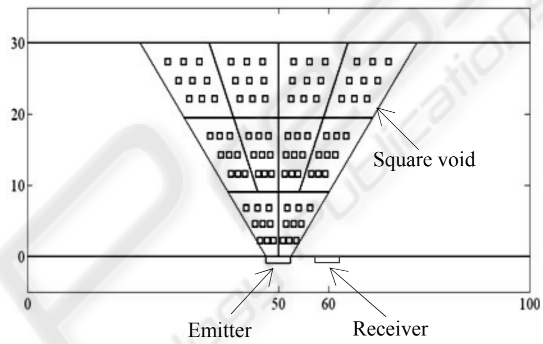

Figure 3: 10 classes of defect in the radiation field.

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