Comparative analysis of Auto-associative NNs and SVMs applied to patterns classification in the damage detection system

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Abstract

The paper presents briefly a principle functioning of a structure health monitoring (SHM) system which utilizes the phenomenon of elastic waves propagation and soft computing methods. Efficiency and robustness of the design SHM system was verified based on signals measured in laboratory strip specimen. Piezoelectric transducers technology was used here in order to actuate and sense elastic waves signals. Following a procedure of signal de-nosing a principal component analysis (PCA) was computed and then a number of signal parameters were used for training the SHM system. In this study, a binary decision tree and support vectors machines (SVMs) were applied for multi-level pattern classification. The obtained results were discussed and compared with those related to previously used Auto-associative Neural Networks (ANNs). On this basis, conclusions were drawn on a performance obtained of the classifiers studied.

Keywords: soft computing, structural monitoring, damage, identification, waves

1. Introduction

The assessment of structures integrity and an early failures detection may be performed using SHM systems. Taking advantage of smart materials application, advanced signals processing and soft computing methods [1] it becomes possible to obtain better precision autonomous systems that may be integrated with structures.

The present paper discusses results of novelty detection and damage evaluation based on the elastic waves propagating studied in healthy and damaged laboratory specimens. The signal parameters calculated were used in order to develop two-stage diagnosis system that employs NNs and advanced signals processing techniques. However this paper focuses mainly on application of ANNs and SVM in patterns classification and provide comparative analysis of the obtained results.

2. Description of the SHM system

The first stage of SHM systems, beyond the sensor level which generates the raw data, is signal processing. Recorded wave propagation signals were subjected herein to data cleansing procedure that employed digital filtering and wavelet de-noising. The second stage is feature extraction. Its objective is to magnify the characteristics of the various damage classes and distinguish it from other damage scenarios. Among various waves parameters computed (amplitudes, spectral density, correlation factors, etc.) principal components were used in order to establish first level of damage identification. It allowed to decrease also signal dimension from 2501 to 16 parameters. The next two stages involve identification of structure state and prediction of damage parameters based on defined input vector and soft computing methods used.

First Auto-associative NNs were used for the purpose of novelty detection. In case such trained network is fed with the inputs obtained from a damage state of the system, the novelty index $NI(\mathbf{x}) = \|\mathbf{x} - \hat{\mathbf{x}}\|$, which is defined as the Euclidean distance between the target outputs $\mathbf{x}$ and the outputs of the NN $\hat{\mathbf{x}}$ will increase [2]. If the learning was successful, the index will be $NI(\mathbf{x}) \approx 0$ for data obtained from undamaged state. However, if data is obtained from the damaged system, the novelty index will indicate an abnormal condition providing a value different to zero.

Second alternative solution studied here utilizes Support Vector Machines Binary Decision Tree (SVM BDT) [4]. The example investigated consists of 4 labels related to specimen's condition (undamaged, damaged 1, damaged 2, damaged 3) and for each one classes were assigned as follows: 0, 1, 2, 3. Then, the classes were organized in clusters since there are two outputs only at each level of BDT (Fig. 1). At first stage a structure can be classified as undamaged (0) or damaged (1, 2, 3). Next the damage patterns (1, 2, 3) can be split to those related to the specimen with one damage (1) and more than one damages (2, 3). Finally, the specimen with two and three damages can be identified at the last stage.

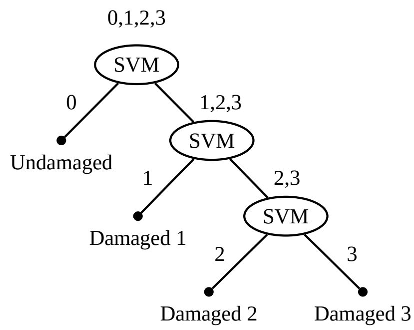

Figure 1: SVM Binary Decision Tree

In case the damage level has been determined a NN defined for damage parameters prediction can be trained. In such the way a damage size or location can be evaluated.

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3. Laboratory tests

The proposed approach of NDT was studied for several laboratory models made of various materials [3]. Nevertheless the main attention in this paper was focused on classification of patterns related to aluminum specimen with damages. As it was already mentioned the applied algorithm takes advantage of advance signal processing techniques, PCA and NNs. Obtained results of novelty detection performed were shown on Fig. 2 and 3. It may be seen that two-level (undamaged, damaged) patterns classification was done perfectly. However, in case of multi-level classification an error has arisen after separation of indirect damage classes.

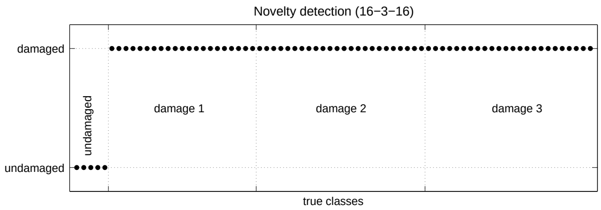

Figure 2: Results of novelty detection applied to aluminum strip - test of NN (16-3-16)

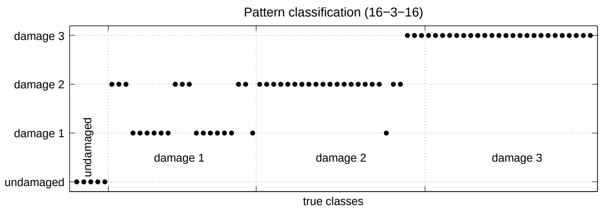

Figure 3: Results of novelty detection applied to aluminum strip - test of NN (16-3-16)

Looking for a better classification accuracy the application of SVM was considered. First, various scenarios of splitting the patterns into training and testing sets were investigated. Logical index vectors for cross-validation of observations was randomly selecting 100 times. The obtained average accuracy for studied kernel functions and respective percentage contribution of testing patterns were collated in Table 1. The results are presented in a form of Correct Rate (CR) defined here as the factor of correctly classified samples and it may reaches values from the $\langle 0, 1\rangle$ interval.

Table 1: Average correct rate of the SVM classifier calculated for the first level of the BDT

Kernel function	Percentage contribution of testing patterns				
	30%	40%	50%	60%	70%
Linear	0.993	0.989	0.974	0.972	0.954
Quadratic	0.996	0.986	0.978	0.970	0.961
Polynomial	0.998	0.991	0.982	0.971	0.955
RBF	0.996	0.990	0.979	0.975	0.960
MLP	0.995	0.989	0.980	0.973	0.958

It can be stated here that despite of minor variation of the CR factor averaged all the studied kernel functions can lead to correct patterns classification. Obviously when the number of testing patterns increases the classification accuracy decreases since decreases also the number of training patterns. However when look at the number of perfectly trained classifiers from all 100 randomly selected training sets it looks even better. For example in case of 3rd order polynomial kernel function the CR in the table corresponds respectively to 97, 86, 65, 46 and 23 correctly trained classifiers with the CR factor equal to 1.

It was assumed for further analysis that patterns classification at certain levels of the BDT will be established using 3rd order polynomial kernel function and 60% of training samples. The results obtained for multi-level classification were shown on Fig. 4. Even with a quite small number of training patterns the correct classification could be achieved. In particular it looks better than in case of ANNs and novelty index used (Fig. 3).

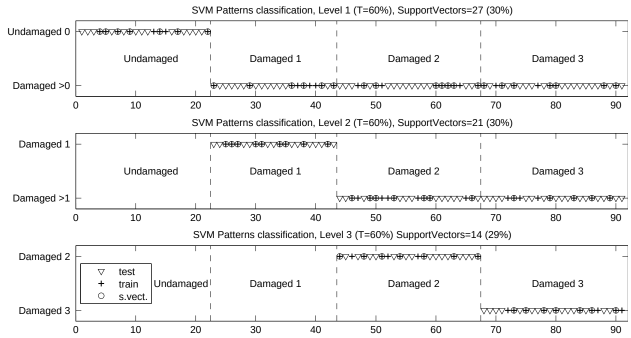

Figure 4: Results of pattern classification using the SVM at the certain levels of the BDT

4. Conclusions

Application of the proposed SHM system allows an automation of inspections, detection of structure's failure states and prediction of damage extent in laboratory models of strip elements. The performed investigations have proved that damage detection and evaluation is possible studying elastic wave propagation. PCA is useful to feature extraction and data reduction for elastic wave signals applied to structure tests. Patterns classification using SVMs BDT exhibit to be more efficient in comparison to ANNs and novelty index. Thanks to this approach correct classification could be carried out at certain levels of the BDT and the improvements of the SHM system accuracy was achieved. The presented approach allows automation of structure test and seems to be very useful for on-line SHM systems. The further development of the system and improvement of damage detection precision may be obtained by searching more suitable feature extraction techniques and studying other types of NNs (e.g. Bayesian NNs).

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