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Ericeira, Portugal, 3-5 July 2017

Numerical investigation on multiclass probabilistic classification of damage location in a plate structure

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Problem statement

taken from www.ptclwg.com

taken from www.rbengineering.com

Solution

nondestructive structural health monitoring methods

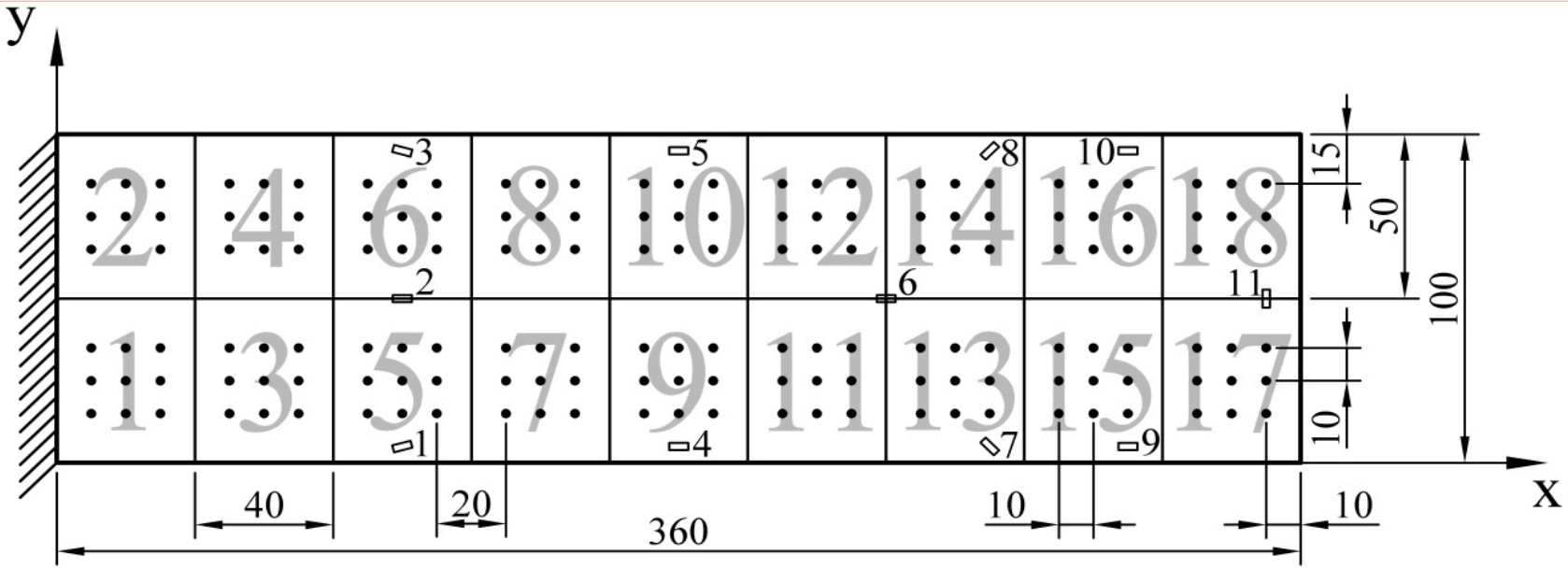
Problem statement

Damage localisation in thin composite structures based on machine learning algorithms

***k*- nearest neighbours**

Decision trees

Specimen model



- **cantilevered CFRP plate** (360 x 10 x 2.4 mm)
- **Laminate lay-up** $[90/90/0/0/45/45/-45/-45/-45/45/0/90]_s$
- $\boldsymbol{E_x = 110\ \text{GPa}, E_y = 7\ \text{GPa}, G_{xy} = G_{yz} = 4.5\ \text{GPa}, \nu_{xy} = 0.33, \rho = 1560\ \text{kg/m}^3.}$
- **11 strain sensors**

Specimen model

ANSYS model – 8-node shear deformable shell elements (72 x 20 elements)

Damage – an artificial mass with 5 % and 10 % fractions of plate's mass is placed at selected nodes of the plate. Additional mass is applied by using **MASS21 finite element**.

Modal analysis (block Lanczos method) to extract **4** eigenfrequencies and eigenmodes.

Classification algorithm

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Class labels

Plate is partitioned into 18 zones

Training

Damage is applied to 9 points in each zone

Data set

Predictors

18 x 9 = 162 data sets with 11 strain values

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Damage localization

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Input strain values for each subzone	→	**162 subzones × 11 strain sensors**
Build a classification model	→ →	*k*-NN (**define *k* and distance**) decision trees (**define max number of splits**)
Calculate resubstitution loss	→ →	*k*-NN (**update *k* and distance to yield minimum**) decision trees (**update max number of splits to yield minimum**)
Cross-validate the model	→	*k*-NN and decision trees (**update K to yield min cross-validation error**)
Make prediction for future data	→ →	Compute **confusion matrix** and **ROC curve** Estimate posterior probabilities
Classify new unknown data in terms of affiliation to any of 18 zones	→ →	**Perform *k*-NN search** **Build a decision tree**

Make a decision regarding location of damage based on majority voting for 5 % and 10 % damage severities

RESULTS

Cross-validation error

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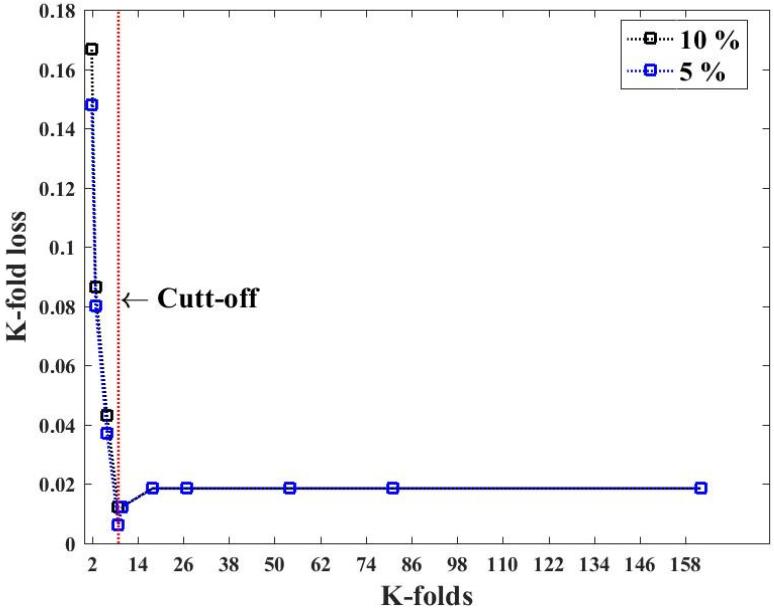
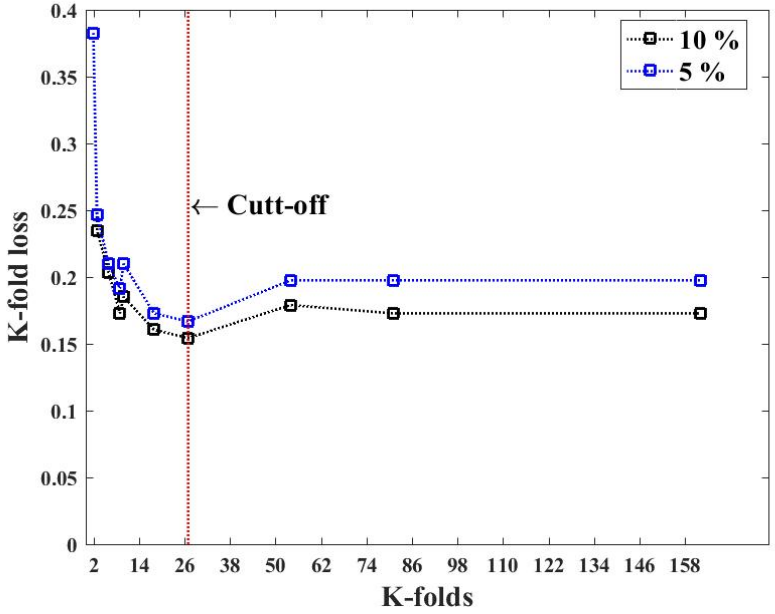
k-NN



Damage severity	10 %	5 %
Number of K-folds	9	9
K-fold loss (%)	0.62	0.62

Decision trees



Damage severity	10 %	5 %
Number of K-folds	27	27
K-fold loss (%)	15.43	16.67

Resubstitution error

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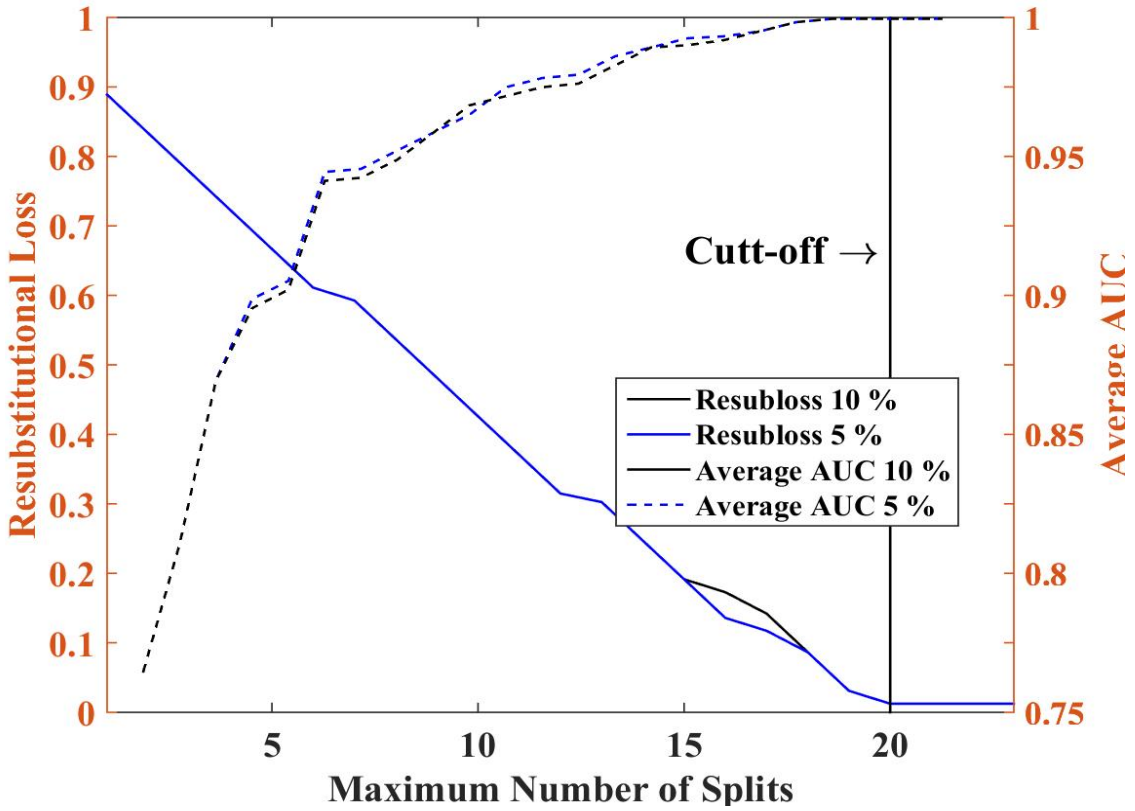

k-NN

Damage severity	10 %	5 %
k	3	3
Resubstitution loss (%)	0	0

Decision trees

Damage severity	10 %	5 %
Maximum number of splits	3	3
Resubstitution loss (%)	1.23	1.23

Confusion matrix

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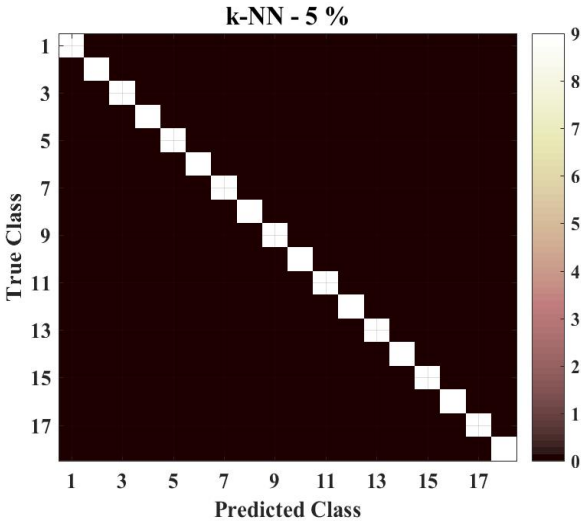
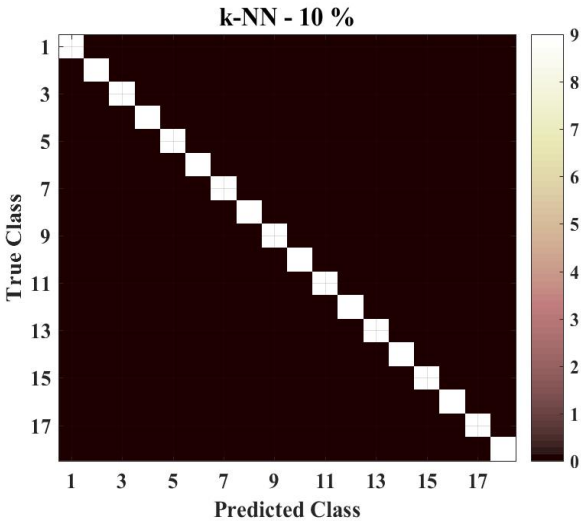
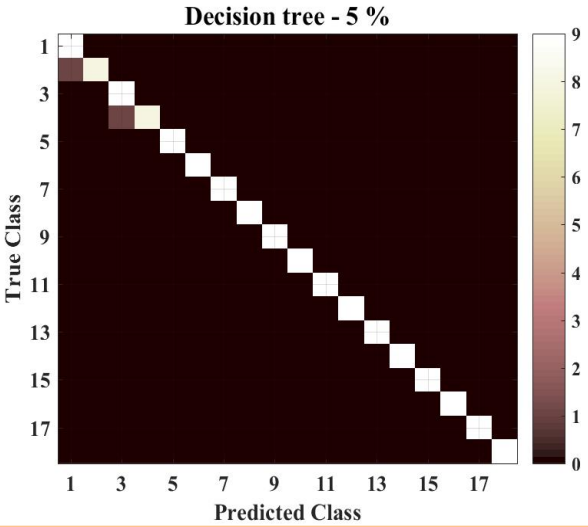
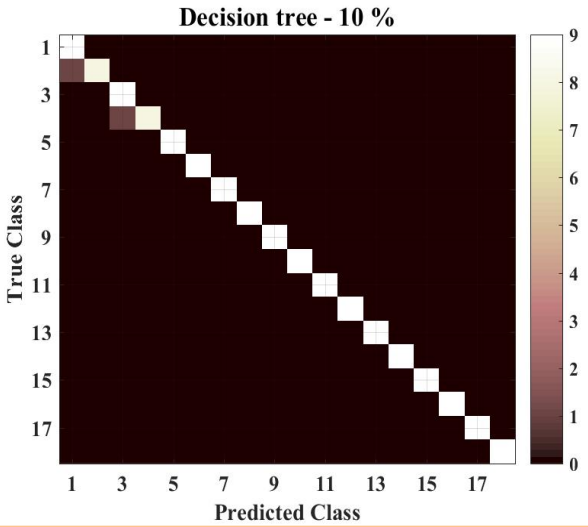


A perfect classification for both damage severities





A slight misclassification in classes no. 2 and 4



ROC curves

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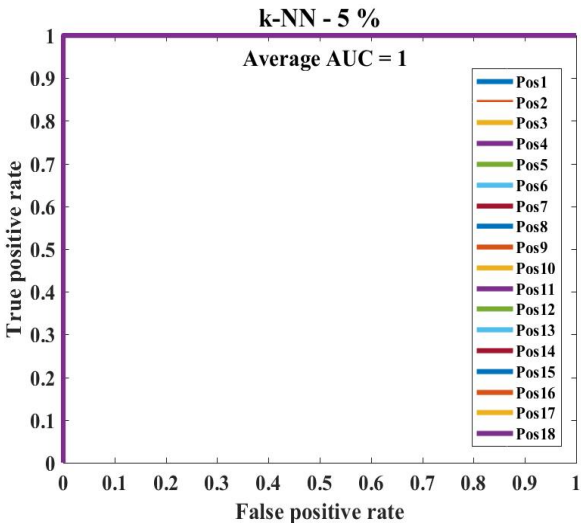
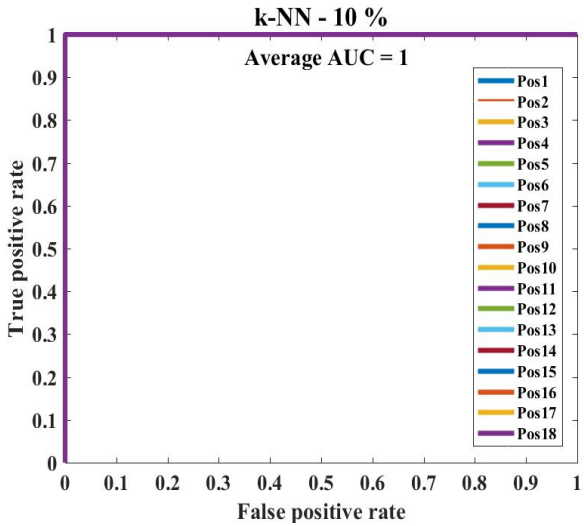
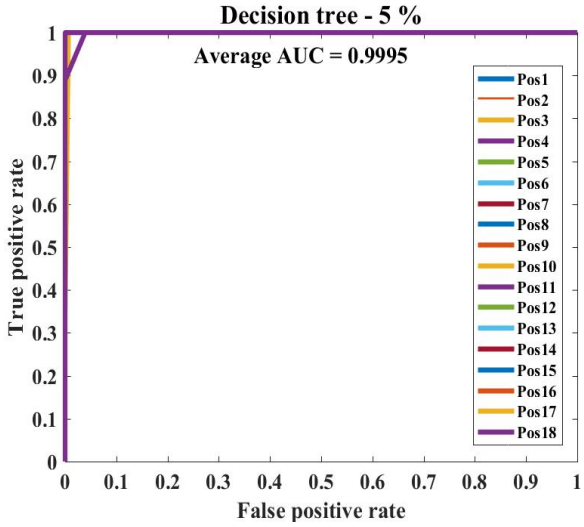


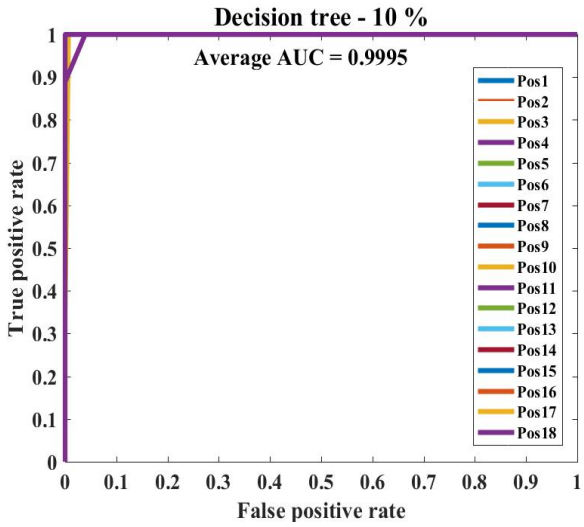
ROC curves are computed for each of 18 classes

AUC is equal to 1





AUC values for all classes are 1, except for classes no. 1, 2, 3 and 4.



Damage localization

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2 new points subjected to classification with k-NN and decision trees

Damage severity 10 %				Damage severity 5 %			
X_1	0.34	Y_1	0.005	X_1	0.13	Y_1	0.035
X_2	0.2	Y_2	0.05	X_2	0.32	Y_2	0.07

Point 1 – zone 17

Point 2 – between zones 9, 10, 11 and 12

Point 1 – zone 7

Point 2 – between zones 16 and 18

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Damage localization

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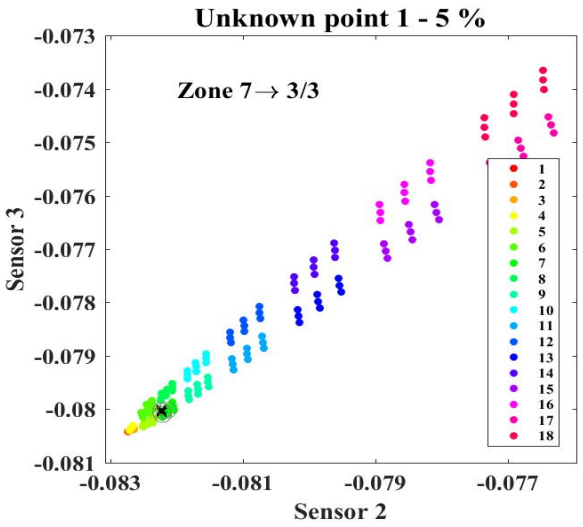
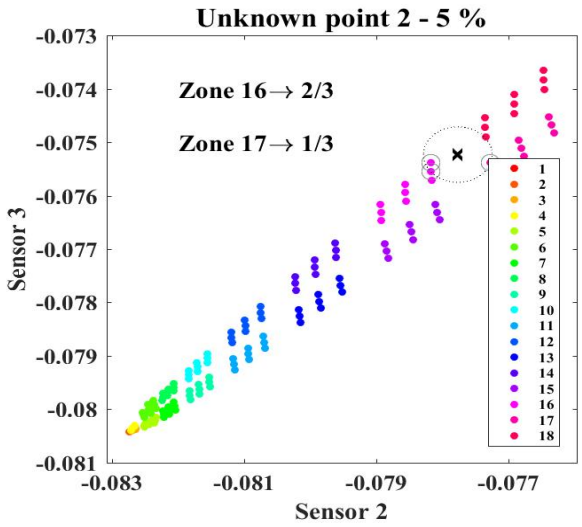
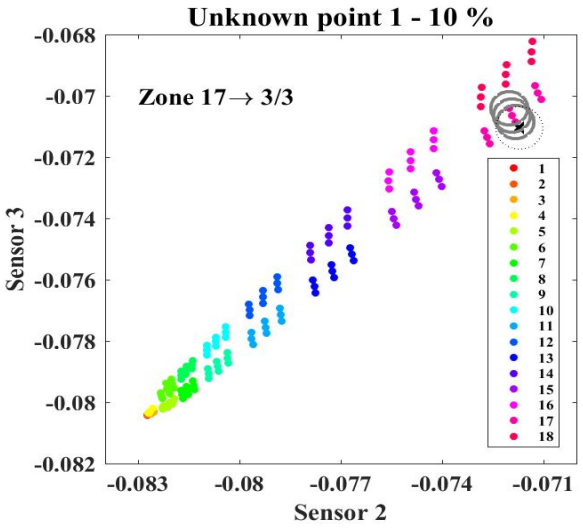
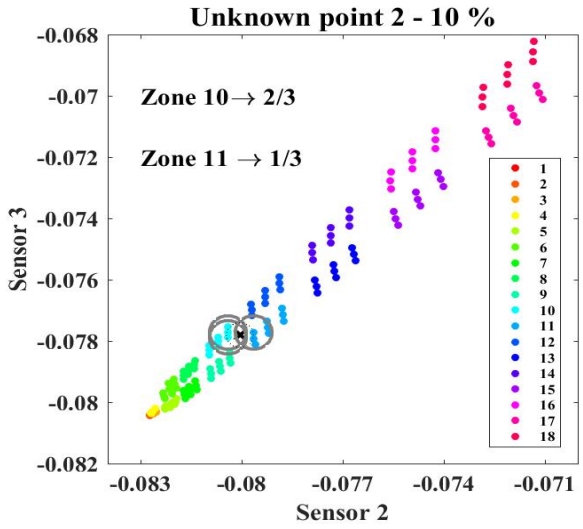


***k*-NN search**







Damage localization

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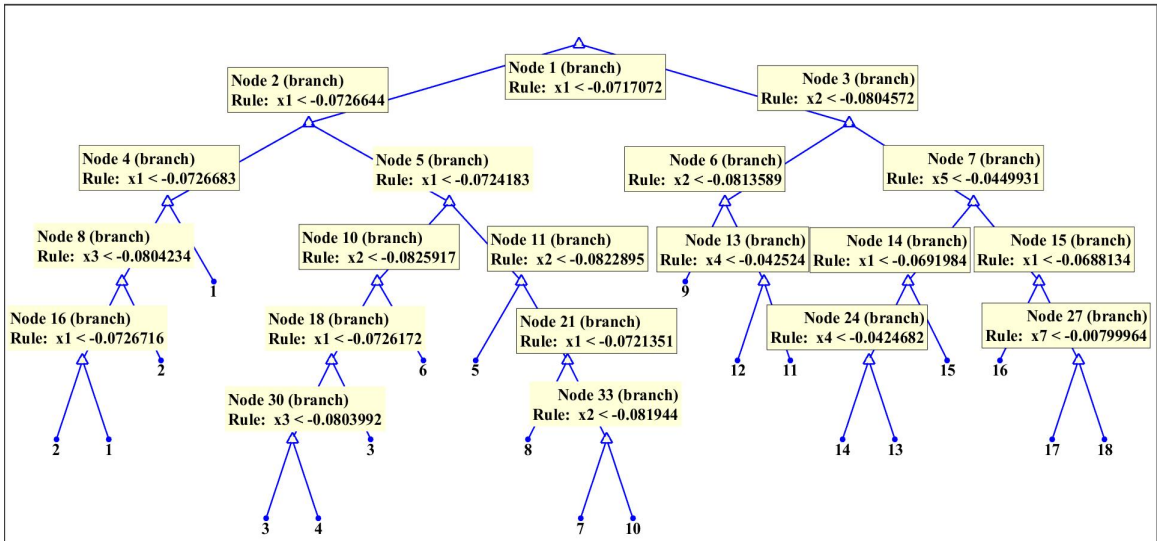
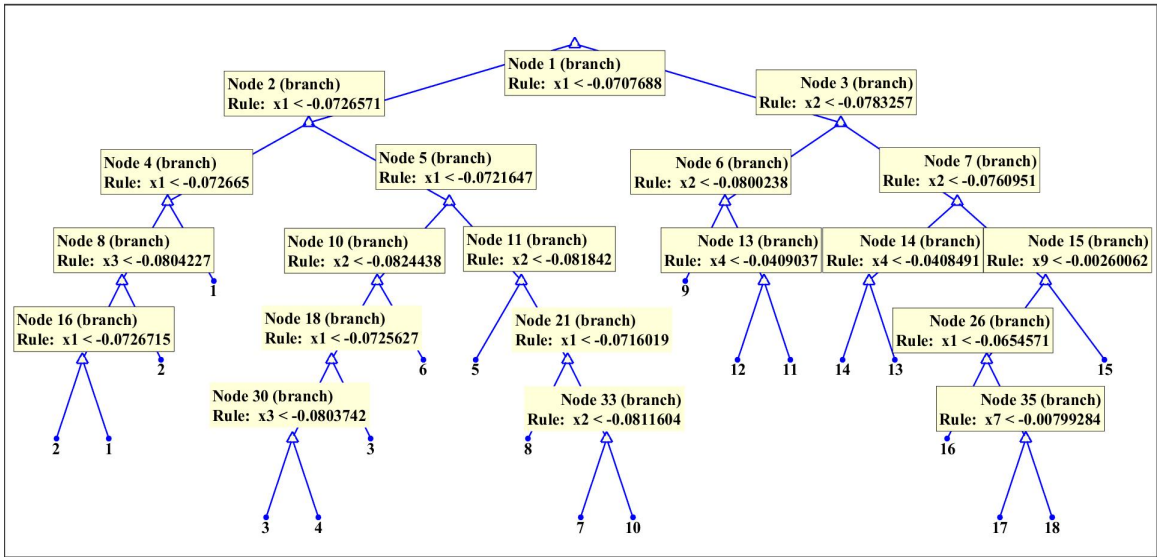


5 %

Unknown point 1 – Zone 7

Unknown point 2 – Zone 18



10 %

Unknown point 1 – Zone 17

Unknown point 2 – Zone 9

Conclusions

- The damage localization methodology for plate structures based on data classification with *k*-NN and decision trees is proposed.
- Classification parameters are optimized to minimize the resubstitution and cross-validation errors.
- The performance of classifiers is assessed through ROC curves with accompanying AUC metric and confusion matrices. These metrics suggest a high quality of classification.
- It is found that there is a good agreement between the localization results of both classifiers and these results are in accordance with the actual coordinates of query points for both severities of damage (5 % and 10 %).

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Thank You for your attention!

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