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*
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 \([90/90/0/0/45/45/-45/-45/-45/45/0/90]_s\)
- \(E_x = 110 \text{ GPa, } E_y = 7 \text{ GPa, } G_{xy} = G_{yz} = 4.5 \text{ GPa, } \nu_{xy} = 0.33, \rho = 1560 \text{ kg/m}^3\)
- 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.
Plate is partitioned into 18 zones

Damage is applied to 9 points in each zone

18 x 9 = 162 data sets with 11 strain values

Predictors
## Damage localization

<table>
<thead>
<tr>
<th>Step Description</th>
<th>Equations/Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input strain values for each subzone</td>
<td>→ 162 subzones × 11 strain sensors</td>
</tr>
</tbody>
</table>
| 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**

### $k$-NN

<table>
<thead>
<tr>
<th>Damage severity</th>
<th>10 %</th>
<th>5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of K-folds</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>K-fold loss (%)</td>
<td>0.62</td>
<td>0.62</td>
</tr>
</tbody>
</table>

### Decision trees

<table>
<thead>
<tr>
<th>Damage severity</th>
<th>10 %</th>
<th>5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of K-folds</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>K-fold loss (%)</td>
<td>15.43</td>
<td>16.67</td>
</tr>
</tbody>
</table>
Resubstitution error

$k$-NN

<table>
<thead>
<tr>
<th>Damage severity</th>
<th>10 %</th>
<th>5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k$</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Resubstitution loss (%)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Decision trees

<table>
<thead>
<tr>
<th>Damage severity</th>
<th>10 %</th>
<th>5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum number of splits</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Resubstitution loss (%)</td>
<td>1.23</td>
<td>1.23</td>
</tr>
</tbody>
</table>
Confusion matrix

A perfect classification for both damage severities

A slight misclassification in classes no. 2 and 4
ROC curves are computed for each of 18 classes.

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

AUC is equal to 1.
2 new points subjected to classification with k-NN and decision trees

<table>
<thead>
<tr>
<th>Damage severity 10 %</th>
<th>Damage severity 5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>X₁ 0.34 Y₁ 0.005</td>
<td>X₁ 0.13 Y₁ 0.035</td>
</tr>
<tr>
<td>X₂ 0.2 Y₂ 0.05</td>
<td>X₂ 0.32 Y₂ 0.07</td>
</tr>
</tbody>
</table>

Point 1 – zone 17
Point 2 – between zones 9, 10, 11 and 12

Point 1 – zone 7
Point 2 – between zones 16 and 18
Damage localization

$k$-NN search
Damage localization

- **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!**