Classification of Compressor Blades Mode Shapes using Convolutional Neural Networks (CNN)

Data Analysis and Machine Learning - Module 3 - Project

Davide Scandella

12 March 2021

University of Bern

Overview

Background

Inputs & Method

Target Accuracy

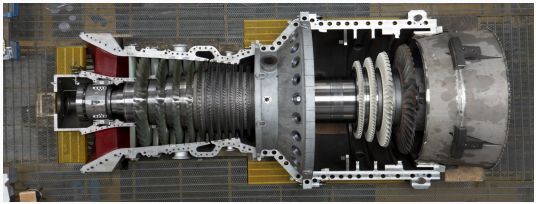
Model Training

Results

Conclusions & Next Steps

Background

Background



From ansaldoenergia.com and cblade.it

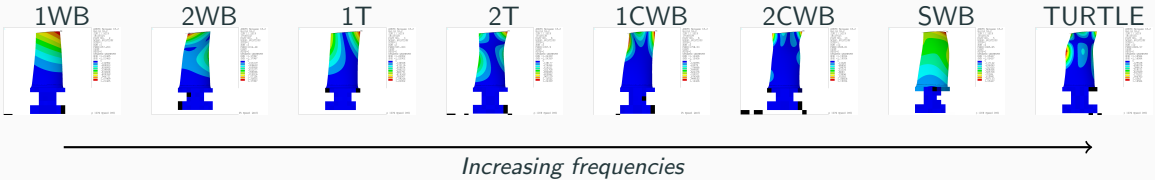
Design of gas-turbine components needs to take into account, among others:

- Eigenfrequencies
- Excitation sources

Target: minimise resonance phenomena during engine operation

Blade natural frequencies

During compressor stage design, blade eigenfrequencies are computed and associated to specific vibrational modes.



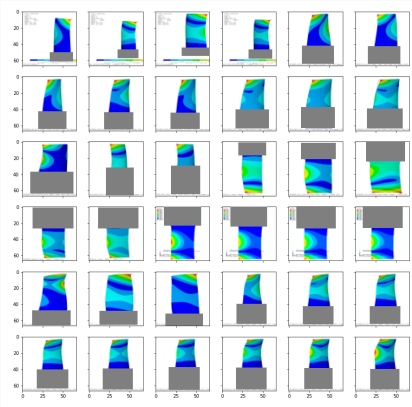
Advantages of automatic mode detection:

- Correlate frequencies and mode shapes during geometry optimisation;
- One-to-one association of mode shapes from FEM to measurements.

Inputs & Method

Inputs

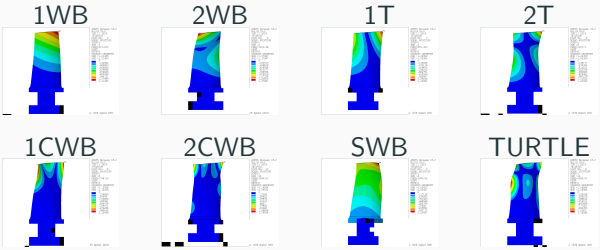
- Blade images taken only from FE modal analyses
- 4 different engines
- 11 stages per engine (avg)
- 373 images
- Crop and resize to 64x64 pixels
- 8 classes due to dataset size
- Split: 85% training, 10% validation
- 5% test (2 unseen compressor stages)



2WB images for different stages

Inputs

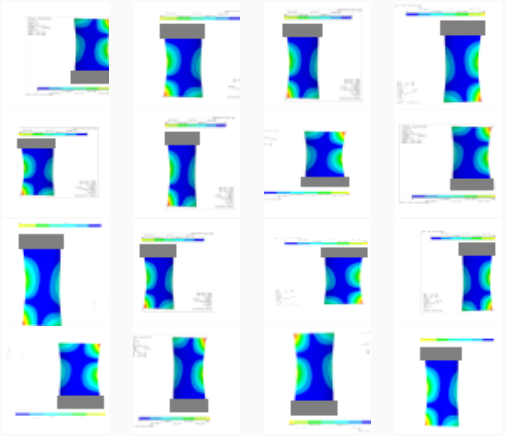
- Blade images taken only from FE modal analyses
- 4 different engines
- 11 stages per engine (avg)
- 373 images
- Crop and resize to 64x64 pixels
- 8 classes due to dataset size
- Split: 85% training, 10% validation
- 5% test (2 unseen compressor stages)



Data Augmentation

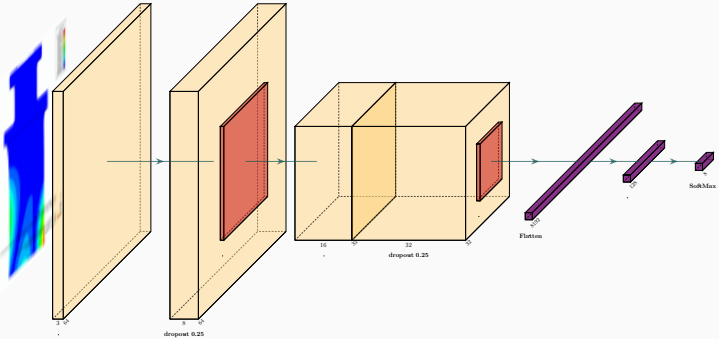
Data is randomly augmented by means of keras *ImageDataGenerator*:

- Horizontal shift $[-23, 23]$ %, fill with white
- Brightness $[80, 125]$ %
- Zoom $[90, 150]$ %
- Channel shift $[-150, 150]$
- Horizontal flip
- Vertical flip
- Rescale values $1./255$



16 randomly-augmented images - same input

Method



- 1.05 *M* parameters *vs* 770 *M* for Fully-Connected NN
- Dropout 25% and Data Augmentation → Overfitting ↓
- Target accuracy is __%

Structure:

- 3 Conv layers
- 2 Max-Pool layers
- 3 FC layers

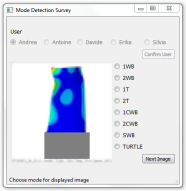
Grid Search:

- Optimizer → Adam
- Learn Rate → 0.001
- Init func → uniform
- Activation → ReLU
- Dropout → 25%

Target Accuracy

Human Benchmark

A survey was carried out among the team

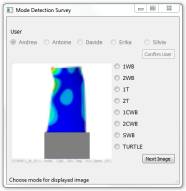


	path character (50)	class character (10)	username character (20)	choice character (20)
1	1CWB_014.png	1CWB	Antoine	1CWB
2	1CWB_014.png	1CWB	Erika	1CWB
3	1CWB_014.png	1CWB	Davide	1CWB
4	1CWB_022.png	1CWB	Erika	1CWB
5	1CWB_022.png	1CWB	Antoine	1CWB
6	1CWB_022.png	1CWB	Davide	1CWB
7	1CWB_031.png	1CWB	Antoine	1CWB
8	1CWB_031.png	1CWB	Erika	1CWB
9	1CWB_031.png	1CWB	Davide	1CWB
10	1CWB_047.png	1CWB	Davide	1CWB
11	1CWB_047.png	1CWB	Antoine	1CWB

89 images out of **100** were classified unanimously by all participants

Human Benchmark

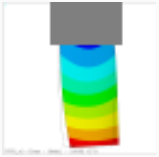
A survey was carried out among the team



	path character (50)	class character (10)	username character (20)	choice character (20)
1	1CWB_014.png	1CWB	Antoine	1CWB
2	1CWB_014.png	1CWB	Erika	1CWB
3	1CWB_014.png	1CWB	Davide	1CWB
4	1CWB_022.png	1CWB	Erika	1CWB
5	1CWB_022.png	1CWB	Antoine	1CWB
6	1CWB_022.png	1CWB	Davide	1CWB
7	1CWB_031.png	1CWB	Antoine	1CWB
8	1CWB_031.png	1CWB	Erika	1CWB
9	1CWB_031.png	1CWB	Davide	1CWB
10	1CWB_047.png	1CWB	Davide	1CWB
11	1CWB_047.png	1CWB	Antoine	1CWB

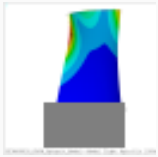
89 images out of **100** were classified unanimously by all participants

SWB



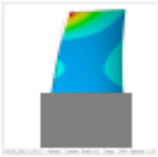
[SWB, 1WB]

1CWB



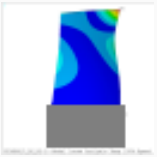
[1CWB, 2CWB]

2WB



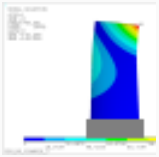
[2WB, 2T]

2T



[2WB, 2T]

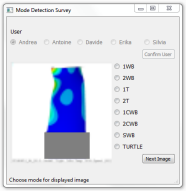
2WB



[2WB, 1T]

Human Benchmark

A survey was carried out among the team



	path character (50)	class character (10)	username character (20)	choice character (20)
1	1CWB_014.png	1CWB	Antoine	1CWB
2	1CWB_014.png	1CWB	Erika	1CWB
3	1CWB_014.png	1CWB	Davide	1CWB
4	1CWB_022.png	1CWB	Erika	1CWB
5	1CWB_022.png	1CWB	Antoine	1CWB
6	1CWB_022.png	1CWB	Davide	1CWB
7	1CWB_031.png	1CWB	Antoine	1CWB
8	1CWB_031.png	1CWB	Erika	1CWB
9	1CWB_031.png	1CWB	Davide	1CWB
10	1CWB_047.png	1CWB	Davide	1CWB
11	1CWB_047.png	1CWB	Antoine	1CWB

89 images out of **100** were classified unanimously by all participants

Sources of error:

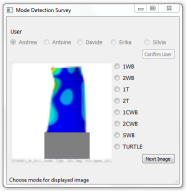
- Distraction
- User experience
- No info on other modes within batch
- No possibility of further checks

Target

Target for the model is __% accuracy

Human Benchmark

A survey was carried out among the team



	path character (50)	class character (10)	username character (20)	choice character (20)
1	1CWB_014.png	1CWB	Antoine	1CWB
2	1CWB_014.png	1CWB	Erika	1CWB
3	1CWB_014.png	1CWB	Davide	1CWB
4	1CWB_022.png	1CWB	Erika	1CWB
5	1CWB_022.png	1CWB	Antoine	1CWB
6	1CWB_022.png	1CWB	Davide	1CWB
7	1CWB_031.png	1CWB	Antoine	1CWB
8	1CWB_031.png	1CWB	Erika	1CWB
9	1CWB_031.png	1CWB	Davide	1CWB
10	1CWB_047.png	1CWB	Davide	1CWB
11	1CWB_047.png	1CWB	Antoine	1CWB

89 images out of **100** were classified unanimously by all participants

Sources of error:

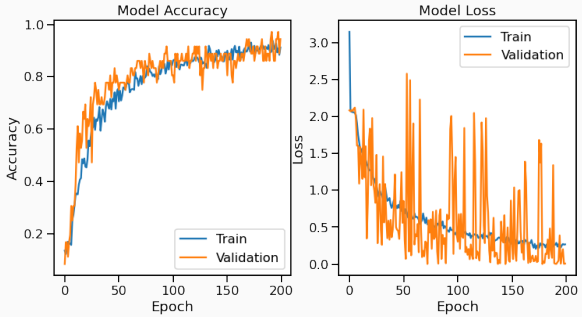
- Distraction
- User experience
- No info on other modes within batch
- No possibility of further checks

Target

Target for the model is 89% accuracy

Model Training

Model Training



The model is trained on:

- 200 epochs
- Batch size: 16

Training Results

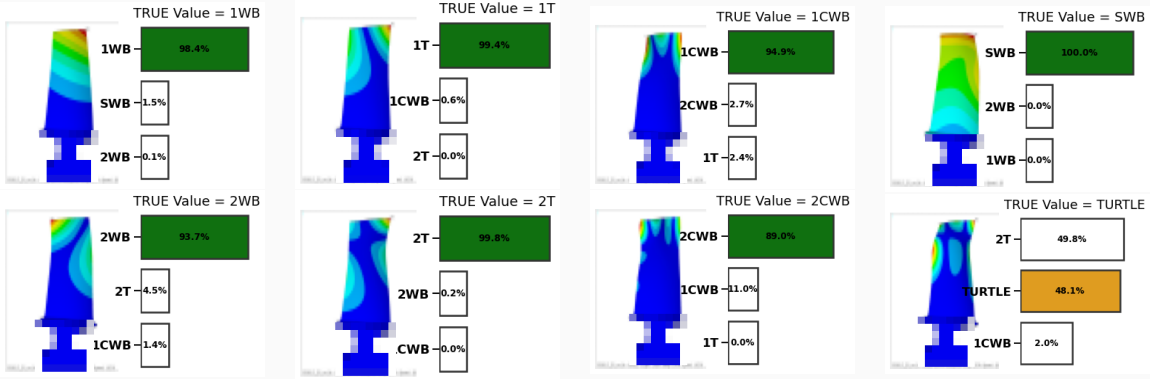
- **Accuracy**: Training and validation reach a value $> 90\% \rightarrow$ Target achieved;
- **Loss**: Loss curve is volatile due to small dataset used for validation;
- **Trade-off** between getting the most out of training keeping validation set reasonably big.

Results

Test accuracy

The performance of the model is evaluated on a test set.

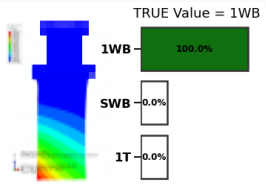
Stage 1

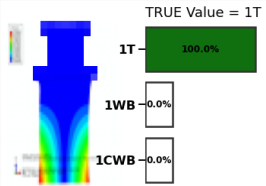


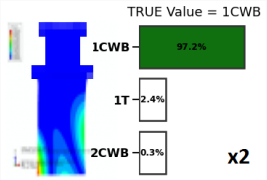
Test accuracy

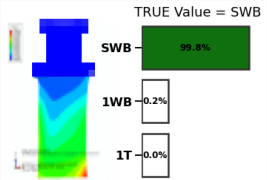
The performance of the model is evaluated on a test set.

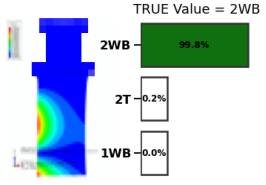
Stage 2

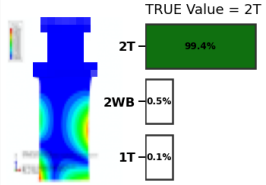


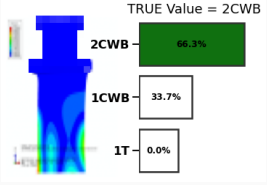


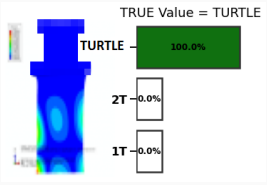








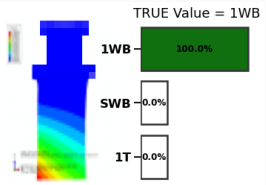


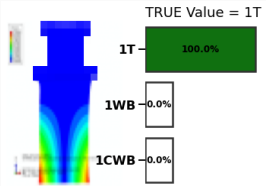


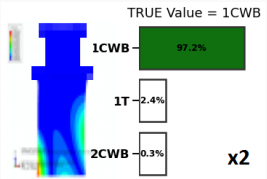
Test accuracy

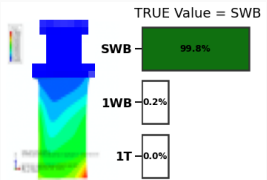
The performance of the model is evaluated on a test set.

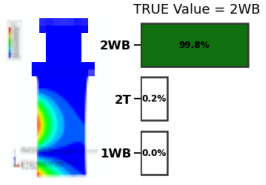
Stage 2

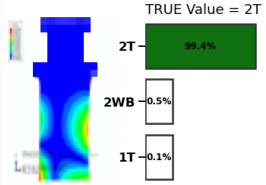


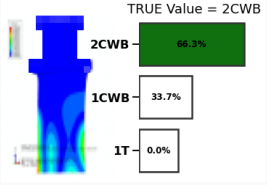


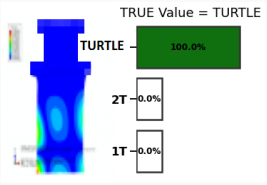






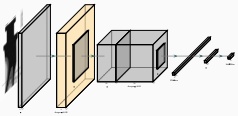




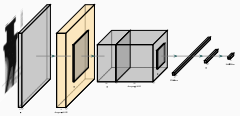


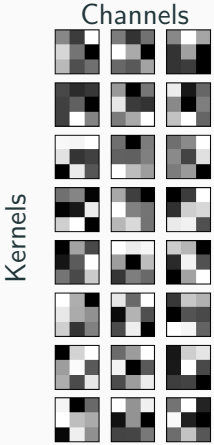
Total accuracy on test set: 94.1 %

Network insights

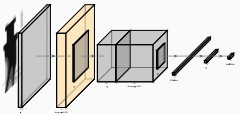


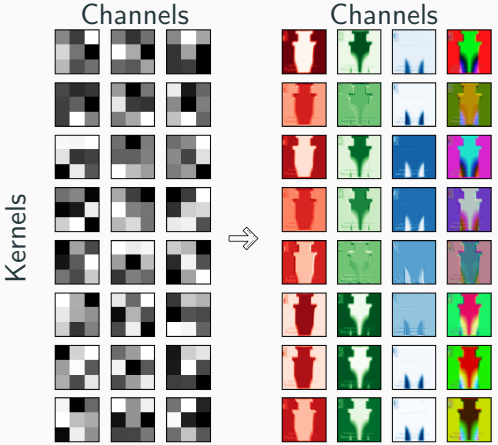
Network insights



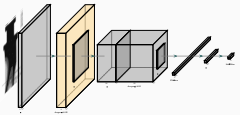


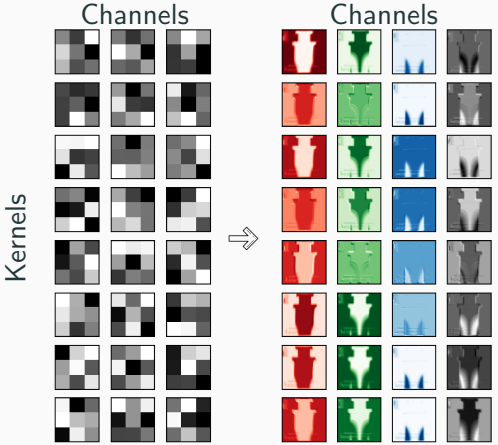
Network insights



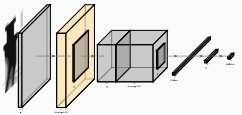


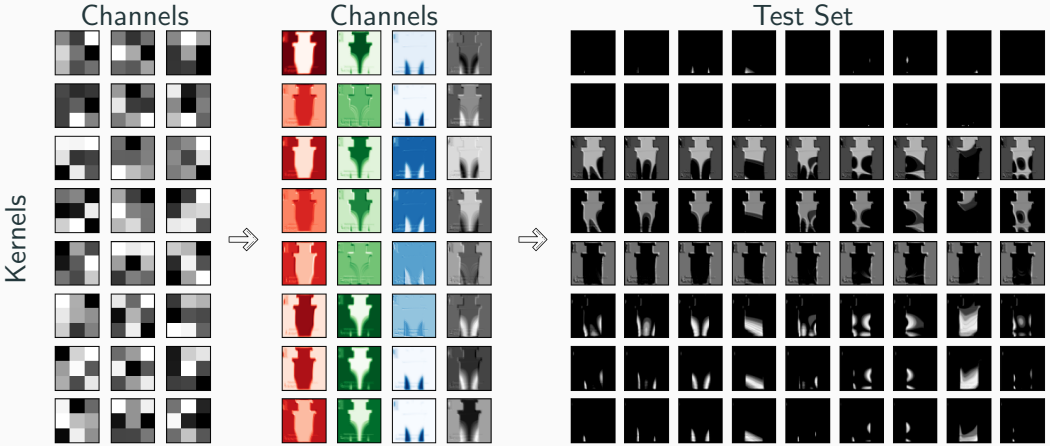
Network insights



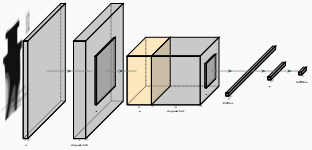


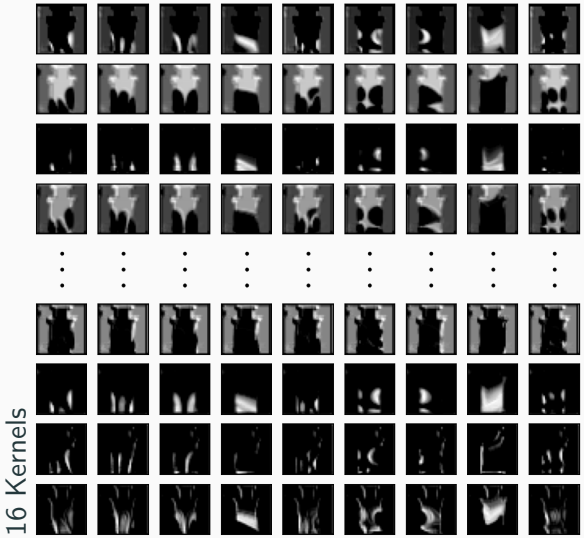
Network insights



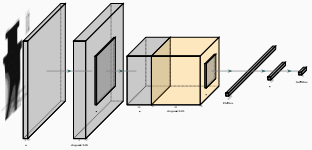


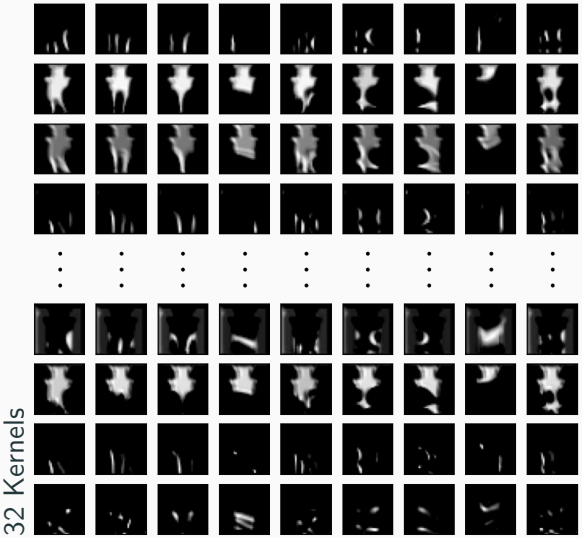
Network insights



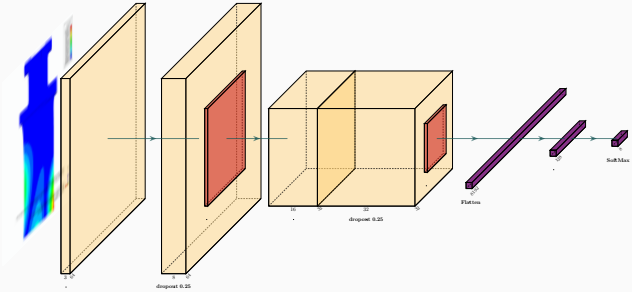


Network insights





Network insights



Insights in a nutshell

- Deeper CNN layers have a bigger receptive field on the input image;
- Feature extraction advances over consequent convolutions;
- But.. network complexity easily leads to overfitting.

Conclusions & Next Steps

Conclusions & Next Steps

Conclusions:

- CNN model has been trained on augmented dataset;
- Limited-size dataset $\rightarrow$ Volatile validation loss;
- Number of classes limited to 8;
- Target $> 90\%$ accuracy achieved.

Next Steps:

- Investigate possibilities to increase dataset size;
- Assess improvement of validation loss upon dataset increase;
- Define approach for additional mode shapes;
- Investigate performance of more complex newtorks running on GPU.

Thank you!