Institut für Informationsverarbeitung

Leibniz Universität Hannover

Konzeptvortrag: Time Series-to-Image Encoding for Machinery Health Monitoring with Deep Vision Networks

Structure of this presentation

1. Introduce to the data sets
2. Visualize
3. Conversion process to images
4. Create and train model
5. Results so far
6. Compare to other papers
7. Existing problems
8. Expected solutions
9. Plan for the rest of the time

Submission date: 25.09.2023

Introduce to the datasets

- Datasets FEMTO bearing were provided by FEMTO-ST Institute for IEEE PHM 2012 Data Challenge.
- 6 train bearing and 11 test bearing were tested and validated by the PRONOSTIA experimental platform under three conditions from beginning to end of life. (run to failure)
- Operation conditions:
  - Condition 1: 1800 rpm and 4000 N
  - Condition 2: 1650 rpm and 4200 N
  - Condition 3: 1500 rpm and 5000 N
- Data characteristics:
  - Vibration signals:
    - Horizontal
    - Vertical
  - Temperature signals

Figure 1: Experimental platform PRONOSTIA

Figure 2: Normal and degraded bearings

Introduce to the datasets

- Data characteristics:
  - Vibration signals:
    - Sampling frequency: $f_s = 25600$ Hz
    - Only 2560 samples in 1/10 s sampled
  - Temperature signals:
    - Sampling frequency: $f_s = 10$ Hz
    - Available only in 11/17 bearings

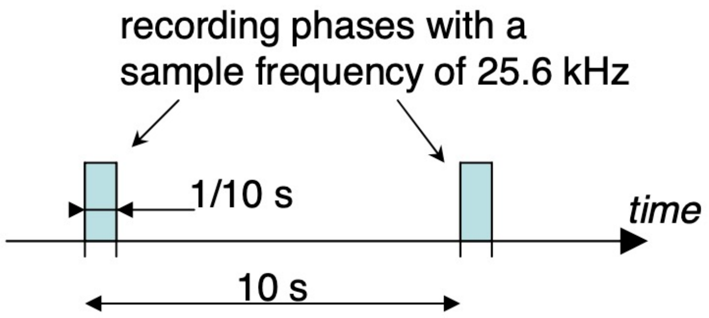

Figure 3: Vibration signals's samples

Table 1: Raw data in .txt file

Characteristics	1	2	3	4	5	6
Vibration signal	Hour	Minute	Second	μ-second	Horizontal accelerometer	Vertical accelerometer
Temperature signals	Hour	Minute	Second	m-second	Rtd Sensor	

Introduce to the datasets

Table 2: Information of bearings

Datasets	Name	Condition	EOL[s]	RUL[s]	n_samples	Characteristics
Train data	Bearing1_1	1	28020	-	7175680	Vibration, Temperature
	Bearing1_2	1	8700	-	2229760	Vibration, Temperature
	Bearing2_1	2	9100	-	2332160	Vibration, Temperature
	Bearing2_2	2	7960	-	2040320	Vibration
	Bearing3_1	3	5140	-	1318400	Vibration, Temperature
	Bearing3_2	3	16360	-	4190720	Vibration
Test data	Bearing1_3	1	23740	5730	4613120	Vibration
	Bearing1_4	1	14270	2890	2915840	Vibration, Temperature
	Bearing1_5	1	24620	1610	5893120	Vibration, Temperature
	Bearing1_6	1	24470	1460	5893120	Vibration, Temperature
	Bearing1_7	1	22580	7570	3845120	Vibration, Temperature
	Bearing2_3	2	19540	7530	3077120	Vibration
	Bearing2_4	2	7500	1390	1566720	Vibration, Temperature
	Bearing2_5	2	23100	3090	5125120	Vibration, Temperature
	Bearing2_6	2	7000	1290	1464320	Vibration
	Bearing2_7	2	2290	580	440320	Vibration
	Bearing3_3	3	4330	820	901120	Vibration, Temperature

Visualize

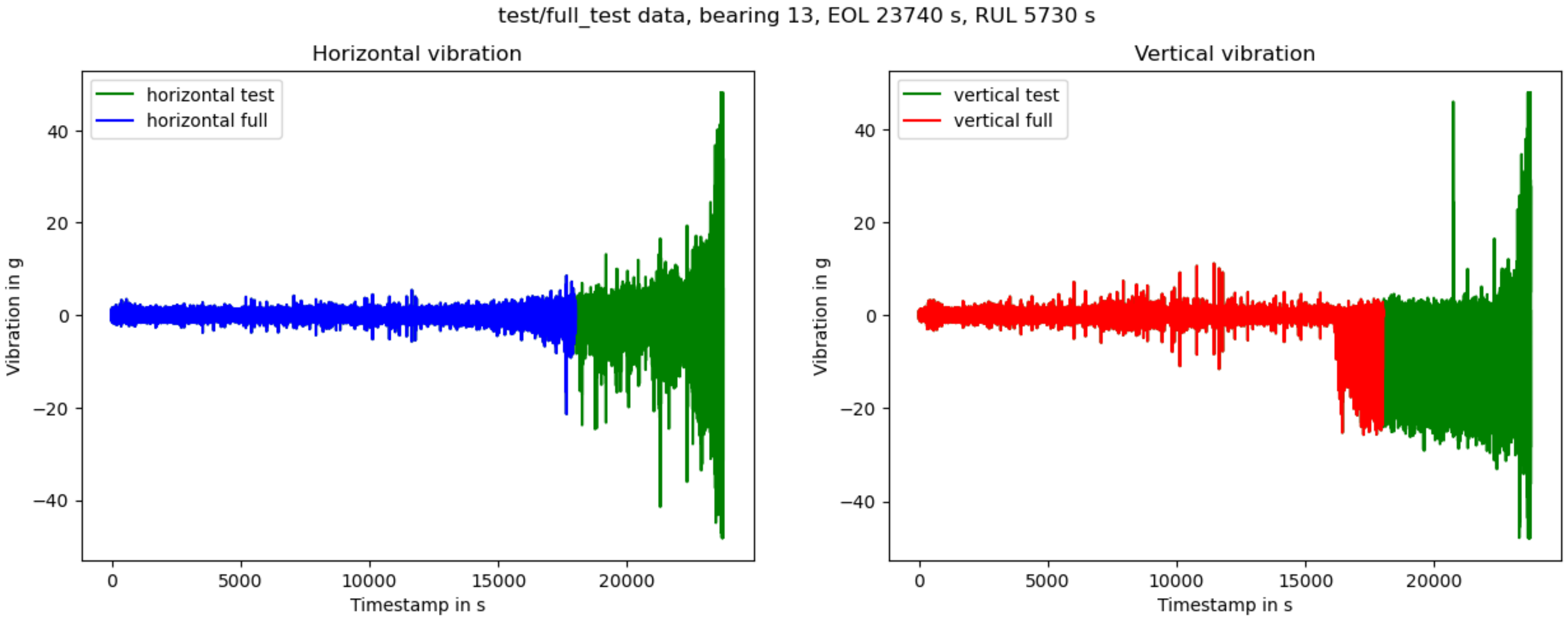

Figure 4: Test bearing 1_3

Conversion process to images

- Windowing

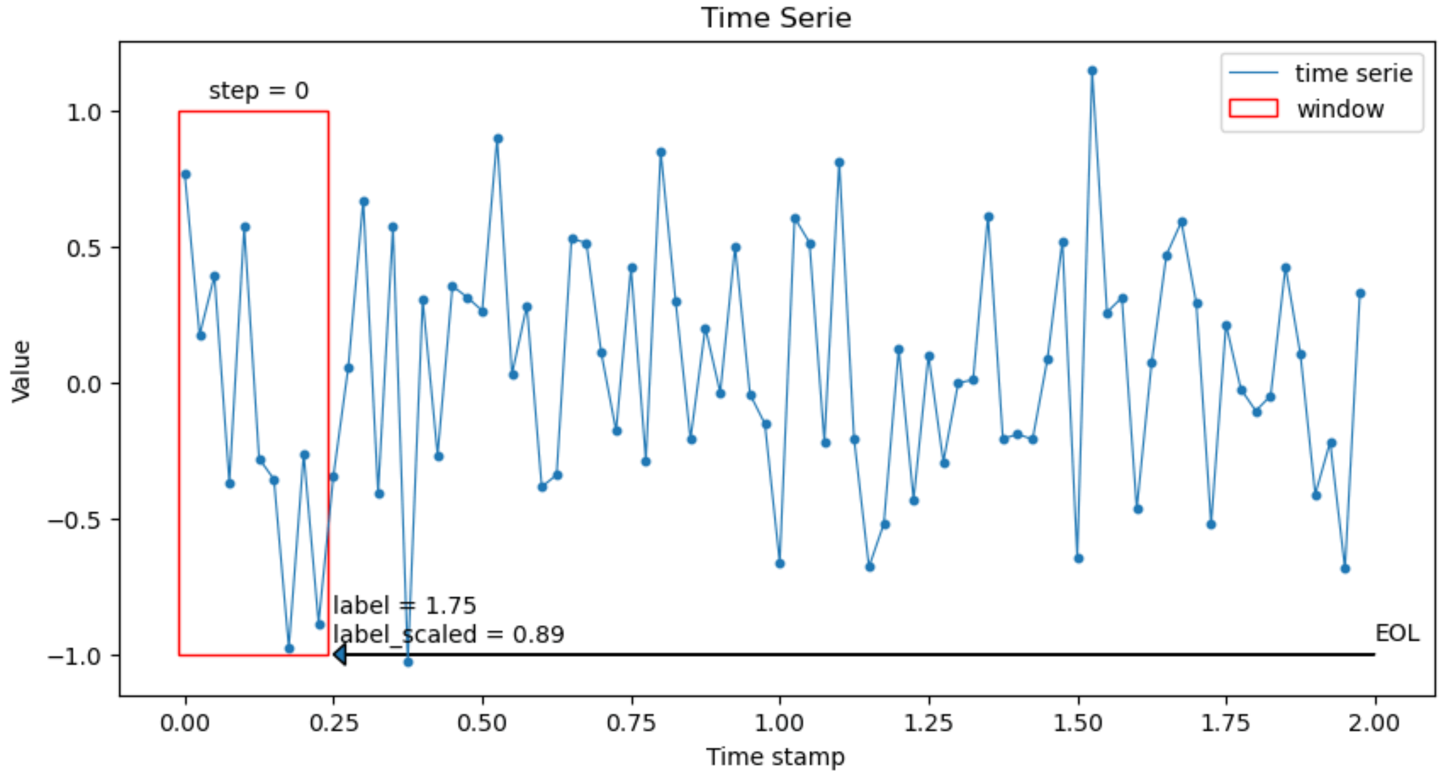

Figure 5: Windowing example

Conversion process to images

- Some time series-to-image transforms will be used in this thesis

Table 3: Time series-to-image transforms.

Scale	Transform	Hyperparameter	Computation cost
Min-Max-Scaler [-1,1]	Recurrence Plot	dimension, time_delay, threshold, percentage	very high
	Gramian Angular Field	method	high
	Markov Transition Field	n_bins, strategy	high
Standardize [0,1]	Continuous Wavelet Transform	scale_min, scale_max, n_scales	medium
	Short Time Fourier Transform	w_stft, h_size	low
	Mel Spectrogram	w_stft, h_size, n_mels	low

Conversion process to image.

- Example: Recurrence Plot
- dimesion = 1
- time_delay = 1
- threshold = 0.5

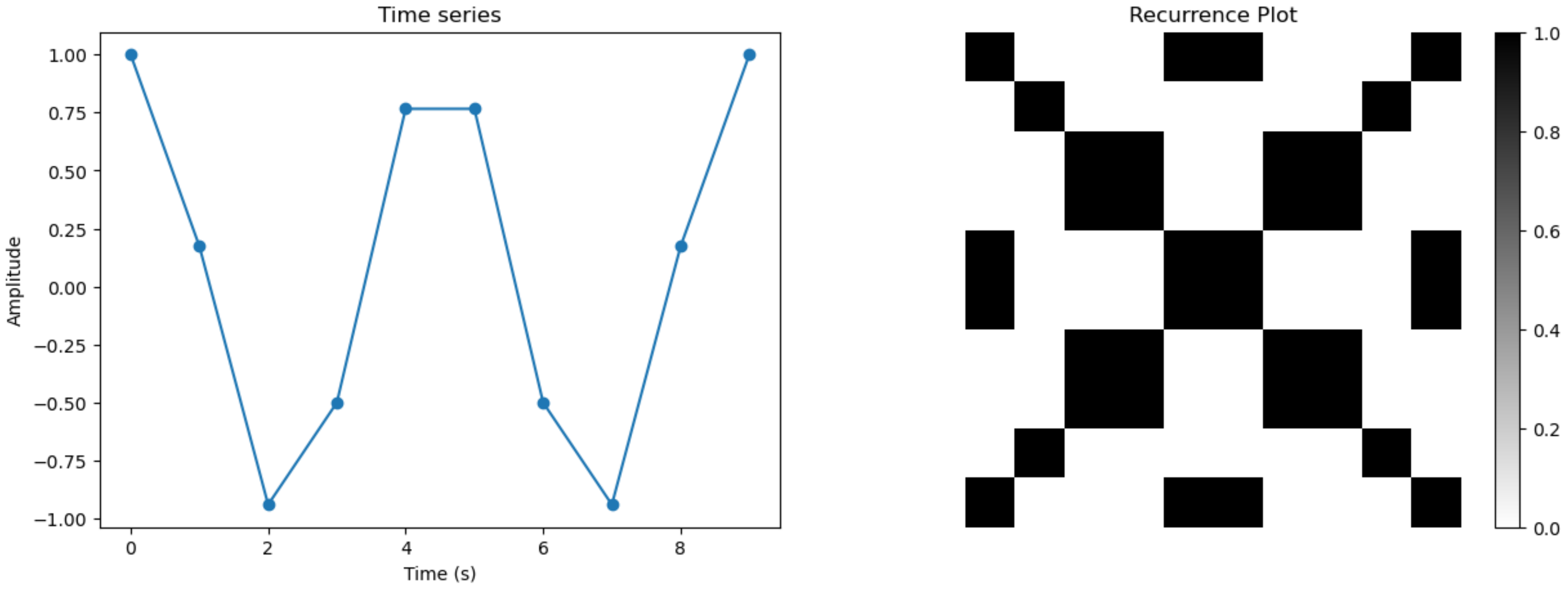

Figure 6: Example RP

Conversion process to image.

- Example: Short-time Fourier Transform
- w_stft = fs / 2
- h_size = fs / 4
- window_name = “hann”

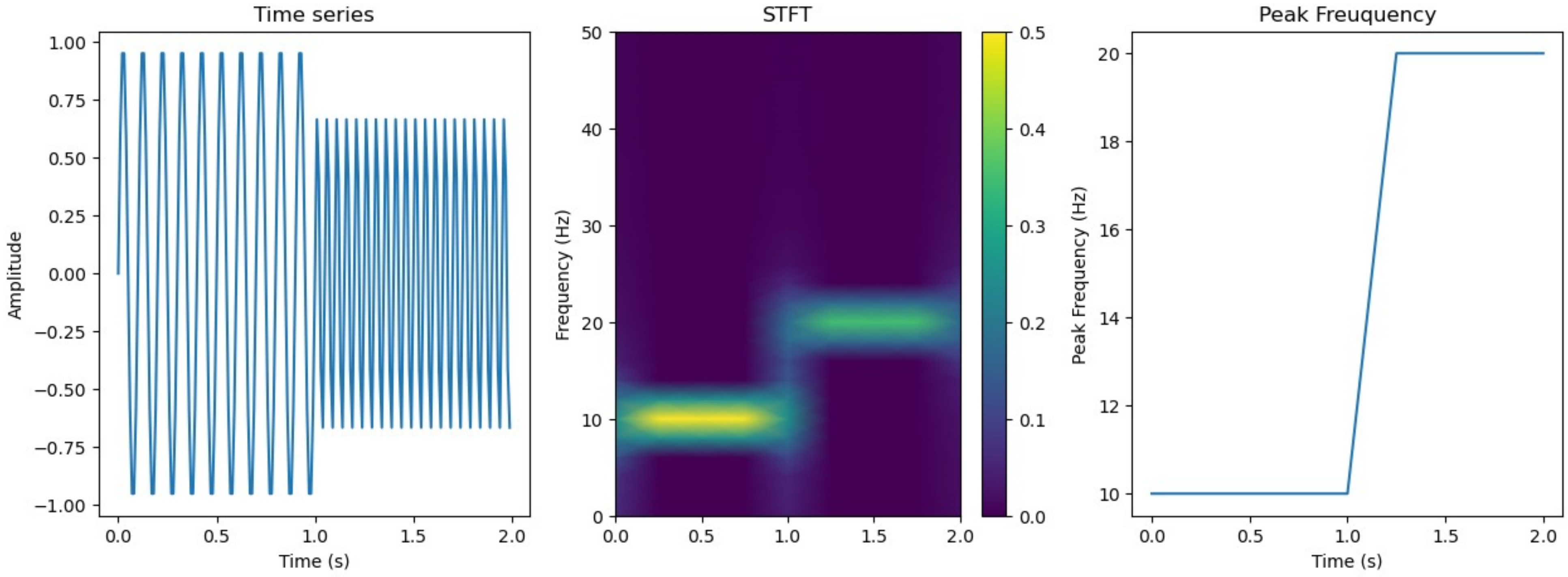

Figure 8: Example STFT

Conversion process to image.

- Example: Continuous Wavelet Transform
- wavelet = “cmor1.5-1”
- min_scale = 2
- max_scale = 12
- n_scales = 100

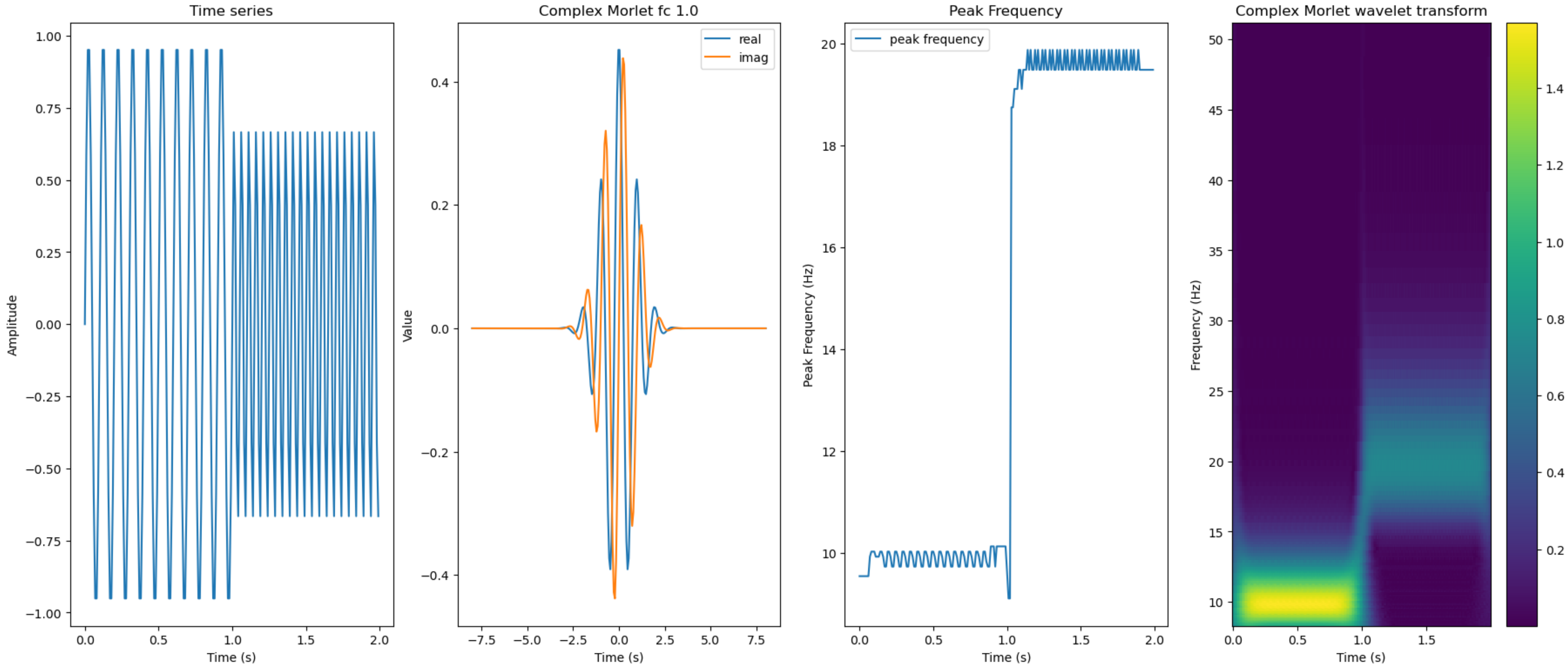

Figure 9: Example CWT.

Conversion process to image.

- Example: Shor-time Fourier transform
- w_size = 25600, hop_size = 2560
- w_stft = 2560, h_size = 256

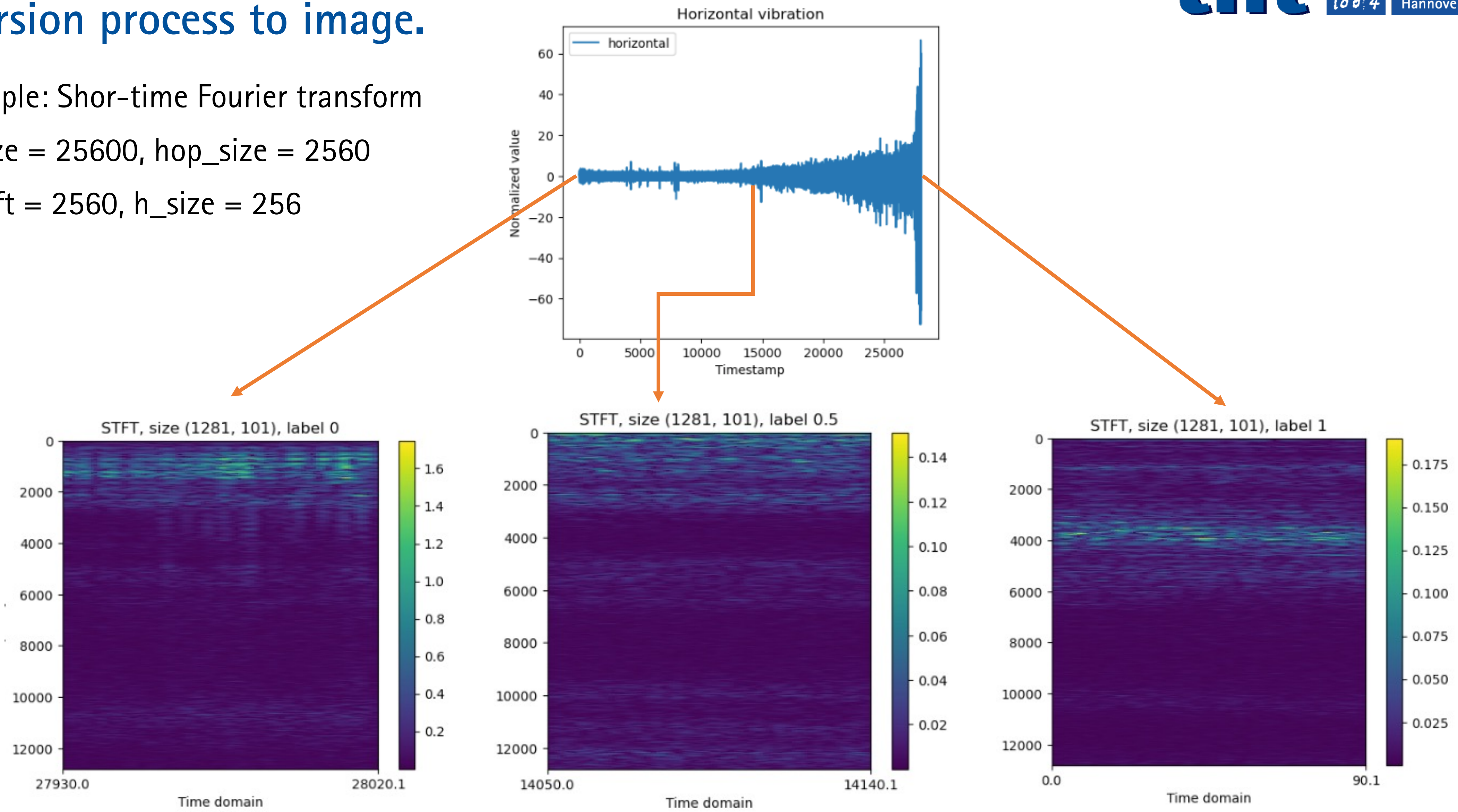

Figure 10: Example STFT

Create and train model

- Structure: EfficientNet-B0
- Input: 3 (default) to 2
- Output: 1000 (default) to 1
- Resize input to (256,256) then center crop to (224,224)

Table 4: Default structure of EfficientNet-B0

Stage	Operator	Resolution	Channels	Layers
1	Conv3x3	224 x 224	32	1
2	MBConv1,k3x3	112 x 112	16	1
3	MBConv6,k3x3	112 x 112	24	2
4	MBConv6,k5x5	56 x 56	40	2
5	MBConv6,k3x3	28 x 28	80	3
6	MBConv6,k5x5	14 x 14	112	3
7	MBConv6,k5x5	14 x 14	192	4
8	MBConv6,k3x3	7 x 7	320	1
9	Conv1x1 & Pooling &FC	7 x 7	1280	1

Create and train model

- Cross validation
  - Fine the best hyperparameters
- Fix hyperparameters:
  - Model's structure: EfficientNet-B0
  - RP, GAF, MTF: Reduce the samples : no
  - STFT, MS: Padding: yes, window_name: hann
  - CWT: wavelet_name: cmor, fc = 1 Hz, b = 1.5
  - K-Fold: 5
  - Hyperparameters tuning optimizer: Tree-structured Parzen Estimator Sampler
  - Loss: MAE
  - Model selection by: Score

Create and train model.

- Score
  - $\%Er_i = 100 \cdot \frac{RUL_{true,i} - RUL_{pred,i}}{RUL_{true,i}}$ wobei $RUL_{true,i}$: actual Remaining Useful Life
    $RUL_{pred,i}$: predicted Remaining Useful Life
  - $A_i = \begin{cases} exp^{-\ln(0.5)\cdot(\frac{Er_i}{5})} & für\ Er_i \le 0 \\ exp^{\ln(0.5)\cdot(\frac{Er_i}{20})} & für\ Er_i > 0 \end{cases}$
  - $Score = \frac{1}{n_{samples}} \sum_{i=1}^{n_{samples}} A_i$
- MAE = $\frac{1}{n_{samples}} \sum_{i=1}^{n_{samples}} \left| RUL_{true,i} - RUL_{pred,i} \right|$

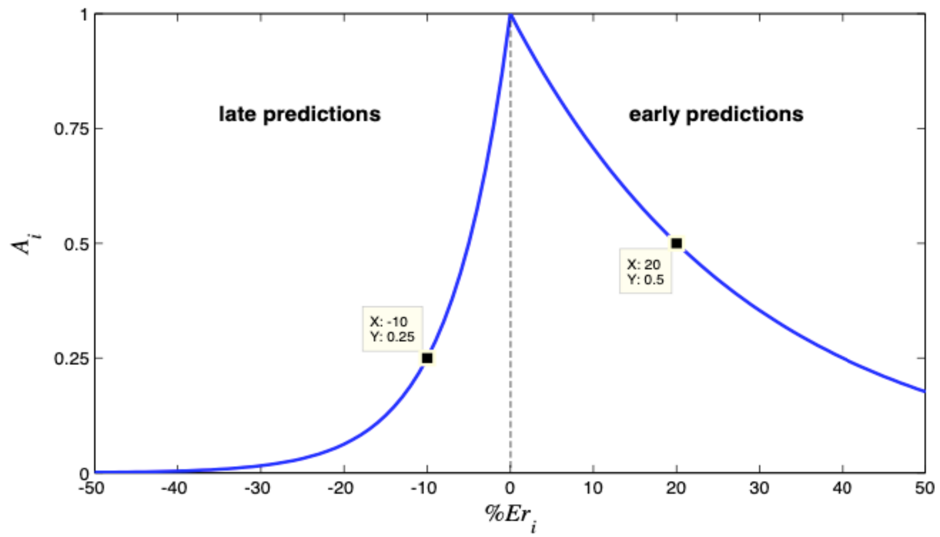

Figure 11: A function.

Create and train model.

- Hyperparameter .

Table 5: Interval of hyperparameter.

Methode	Hyperparameter	Modell hyperparameter
Recurrence Plot	dimension = [1,48,log] time_delay = [1,48,log] threshold = [None, “float“,“distance“,“point“] percentage = [5,80,5]	dropout = [0.1,0.8,log]
Gramian Angular Field	method = [“summation“,“difference“]	optimizer = [“Adam“,“SGD“]
Markov Transition Field	n_bins = [5,15,1] strategy = [“uniform“,“quantile“,“normal“]	learning_rate = [0.0005,0.2,log]
Continuous Wavelet Transform	scale_min = [0.5,5,0.5] scale_max = [10,50,2] n_scales = [50,300,10]	batch_size = [8,100,2]
Short Time Fourier Transform	w_stft =[512,5120,128] hop_stft = [32,512,32]	epochs = [5,50,1]
Mel Spectrogram	w_stft =[512,5120,128] hop_stft = [32,512,32] n_mels = [150,350,10]	

Results so far.

Table 6: Time series-to-image transforms.

Methode	MAE	Score	Final score	Hyperparameter
Recurrence Plot	0.21	0.28	0.06	threshold = "distance", dimension = 47, time_delay = 4, ,batch_size = 100, epochs = 47, dropout = 0.23, optimizer = "Adam", learning_rate = 0.001
Gramian Angular Field	0.22	0.27	0.01	method = "difference", batch_size = 72, dropout = 0.72, epochs = 36, optimizer = "Adam", learning_rate = 0.002
Markov Transition Field	0.19	0.30	0.03	n_bins = 7, strategy = "uniform",batch_size = 78, dropout = 0.33, epochs = 28, optimizer = "Adam", learning_rate = 0.0005
Continuous Wavelet Transform	0.16	0.36	0.09	scale_min = 2.5, scale_max = 46, n_scale = 90 ,batch_size = 82, dropout = 0.60, epochs = 27, optimizer = "Adam", learning_rate = 0.004
Short Time Fourier Transform	0.15	0.40	0.34	w_stft = 1280, hop_stft = 64, batch_size = 28, dropout = 0.113, epochs = 43, optimizer = "SGD", learning_rate = 0.018
Mel Spectrogram	0.22	0.27	0.10	w_stft = 1280, hop_stft = 64, n_mels = 270, batch_size = 28, dropout = 0.113, epochs = 43, optimizer = "SGD", learning_rate = 0.018

Results so far

- Method STFT: loss val: 0.04, score val: 0.62

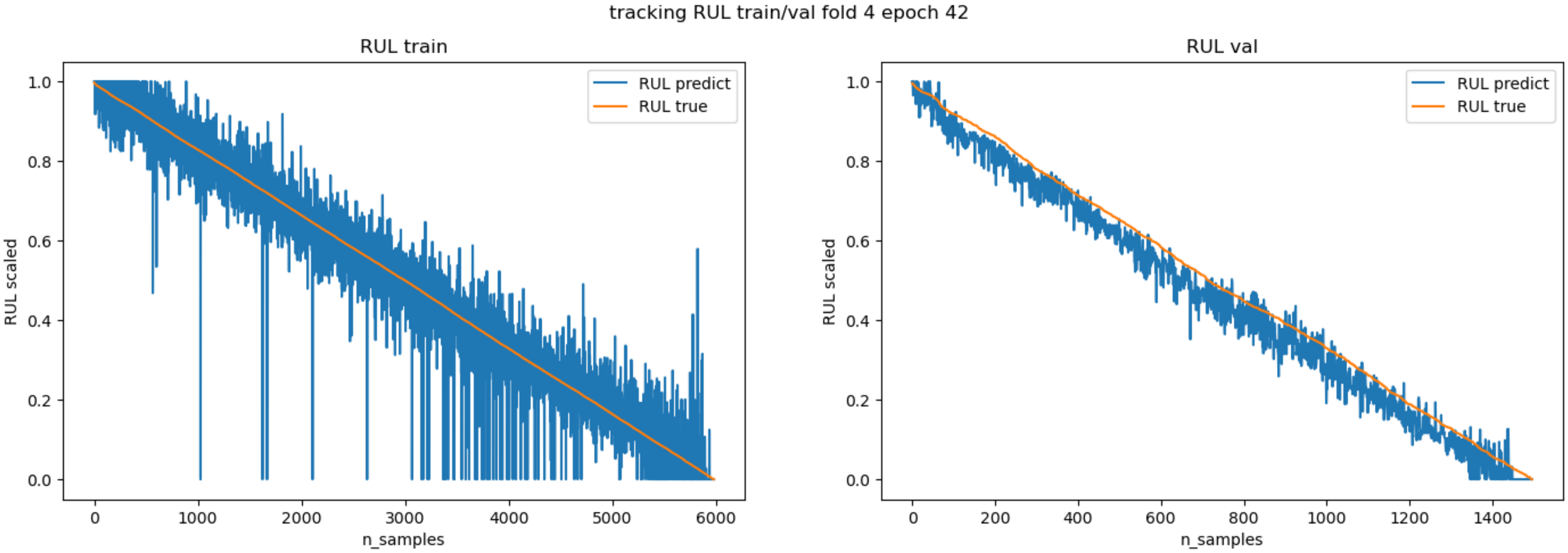

Figure 12: Result of cross validation.

Results so far

- Method STFT

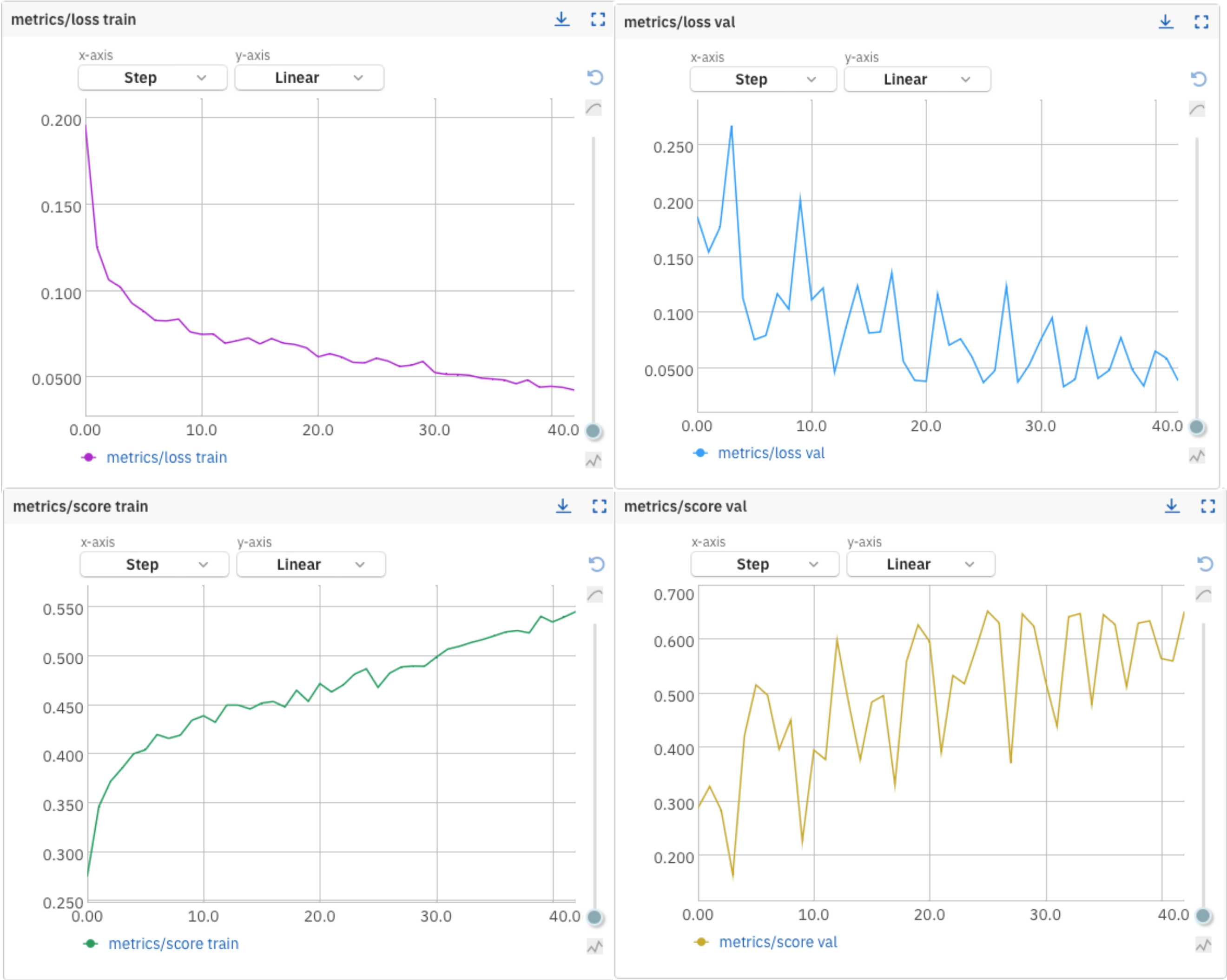

Figure 13: Result of cross validation.

Results so far

- Short-time Fourier transform

Table 7: RUL

Lager	RUL true	RUL pred
13	5730	2616
14	2890	2854
15	1610	3846
16	1460	2438
17	7570	8321
23	7530	7140
24	1390	3184
25	3090	7226
26	1290	1204
27	580	1589
33	820	746
Final score	0.34	
Score	0.40	

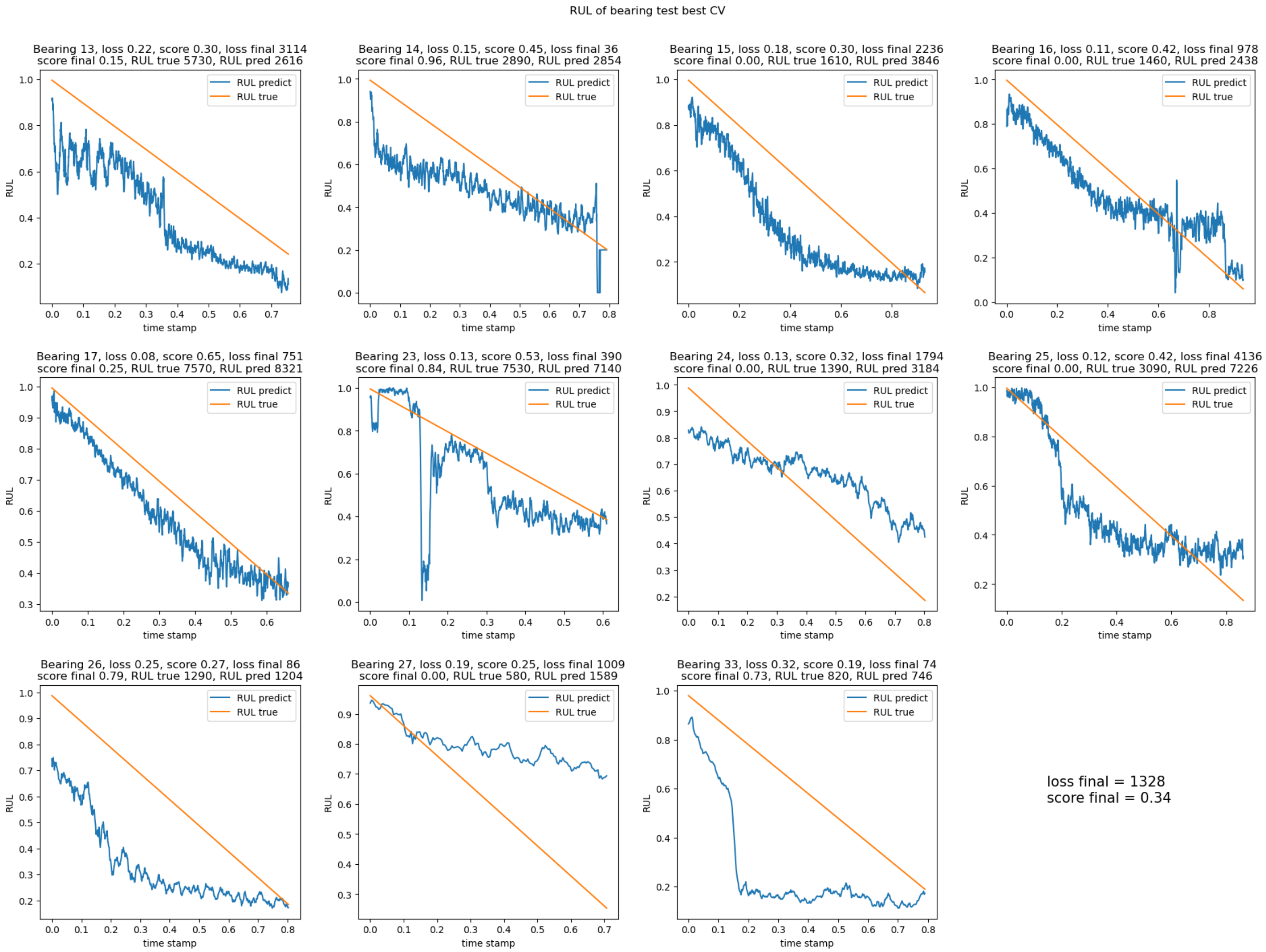

Figure 14: RUL of test bearings.

Compare to others papers

- Proposed method: Short-time Fourier transform with convolutional neural network

Table 8: Results of other papers

	Proposed method	Sutrisno et al., 2012 (Challange winner)	Huang et al., 2012	Lei et al., 2016	Guo et al., 2017	Chen et al., 2019	Zhu et al., 2018 (*)	Wang et al., 2021 (**)
Approach	STFT-CNN	Bayesian Monte Carlo Support Vector Machine Vibration frequency signature anomaly detection	LSTM	Model based	RNN	RNN with Encode-Decode	CWT-CNN	CWT-3D-CNN
Final score	0.34	0.31	0.56	0.43	0.26	0.44	0.36	0.77

(*) Only 5 bearings are considered to calculate final score.
(**) Only 6 bearings are considered to calculate final score.

Existing problems

- Only STFT works well
- Overfitting on other transforms

Expected solutions

- Increase training time
- Fine tune hyperparameter intervals
- Try EfficientnetB1, 2, 3, 4, 5, 6, 7

Plan for the rest of the time

- Try the solutions mentioned above.
- Try Vision Transformer for my problem
- Optimize my code
- Write my bachelor thesis

Thank you for your attention

Conversion process to image.

- Example: Markov Transition Field
- n_bins = 5
- strategy = “quantile”

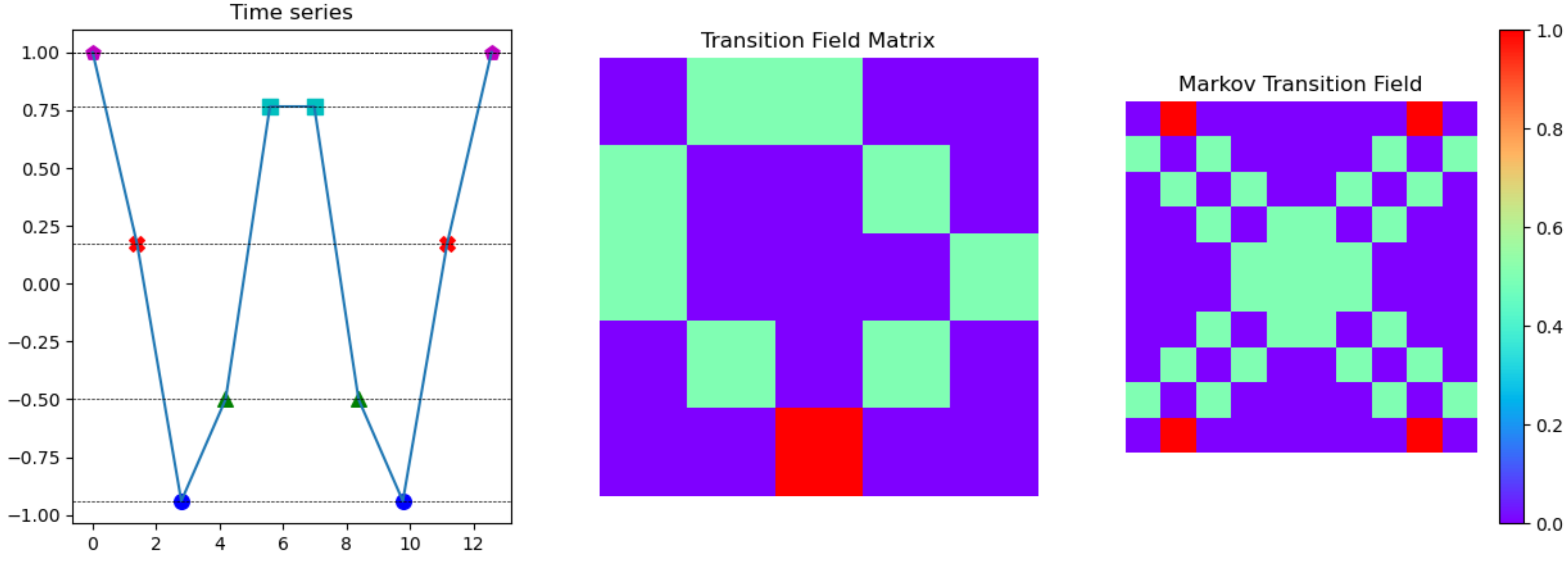

Figure 15: Example GAF

Conversion process to image.

- Example: Gramian Angular Field
- method = “summation”

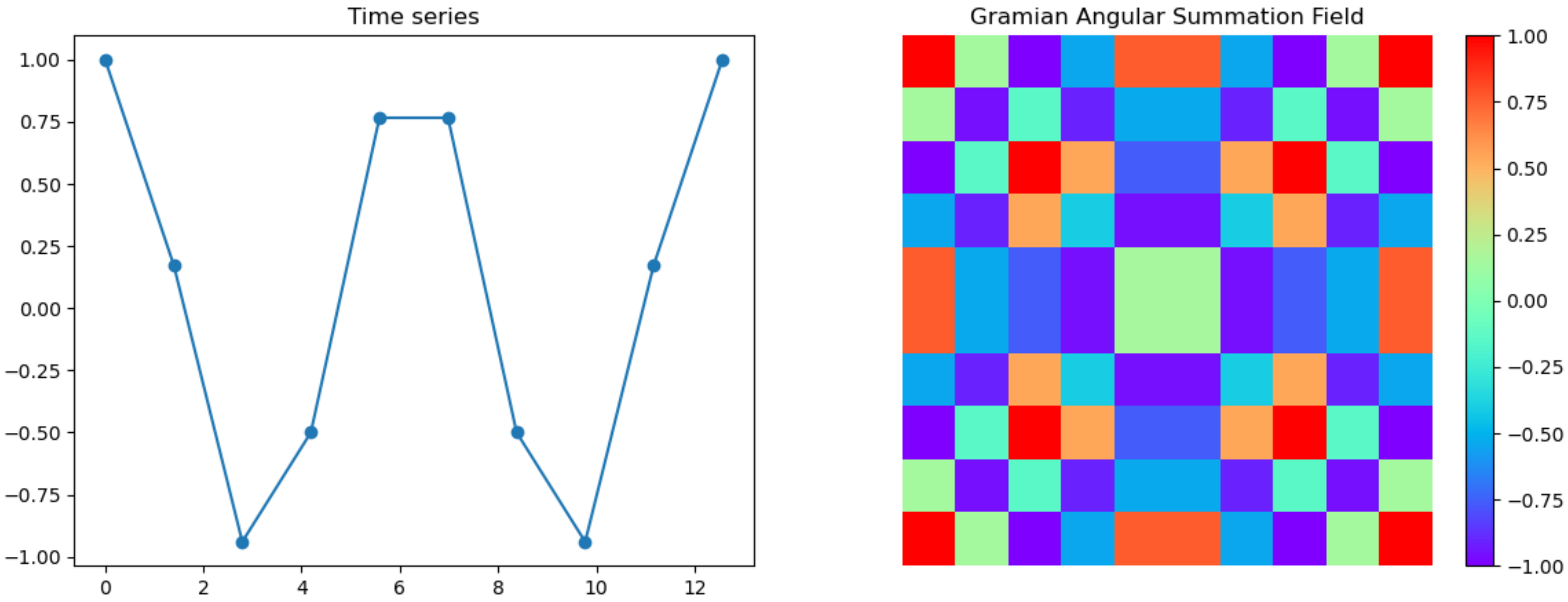

Figure 16: Example GAF

Conversion process to image.

- Example: Mel Spectrogram
- w_stft = fs
- h_size = fs / 20
- window_name = “hann”
- n_mels = 100

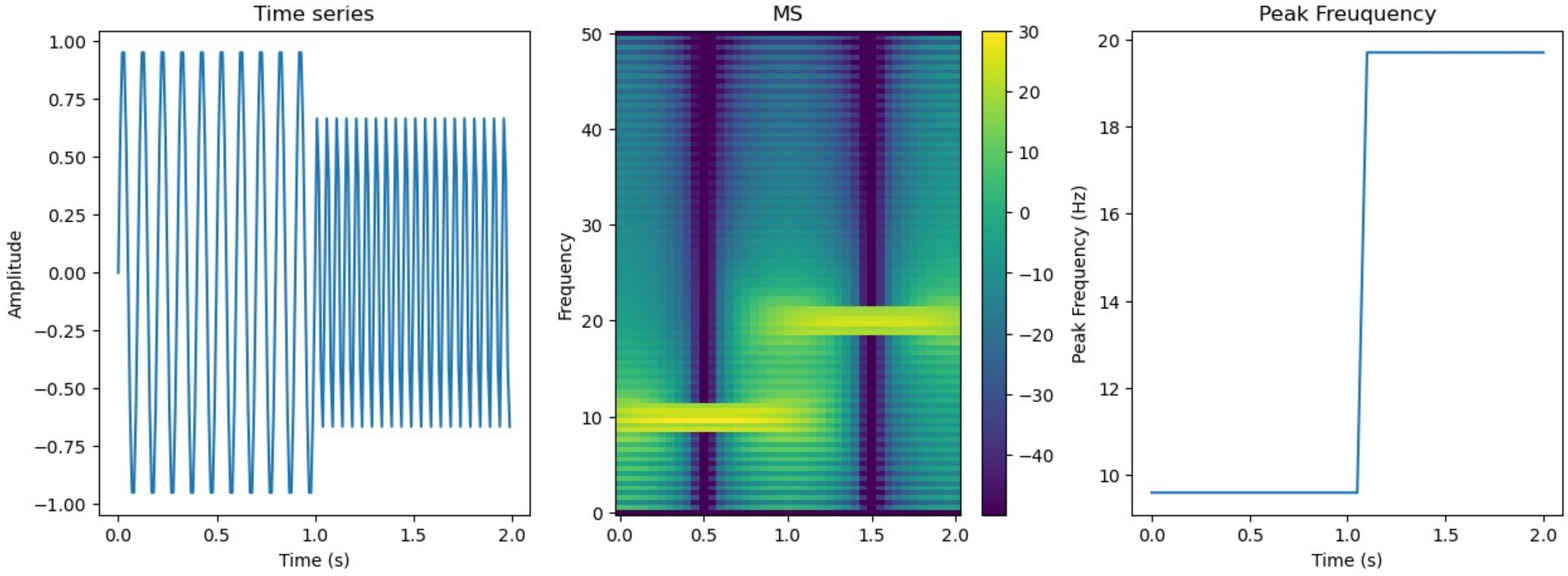

Figure 17: Example MS

Conversion process to image.

- Example: Recurrence Plot.
- w_size = 2560, hop_size = 2560.
- dimension = 1, time_delay = 1.
- threshold = "distance", percentage = 20.

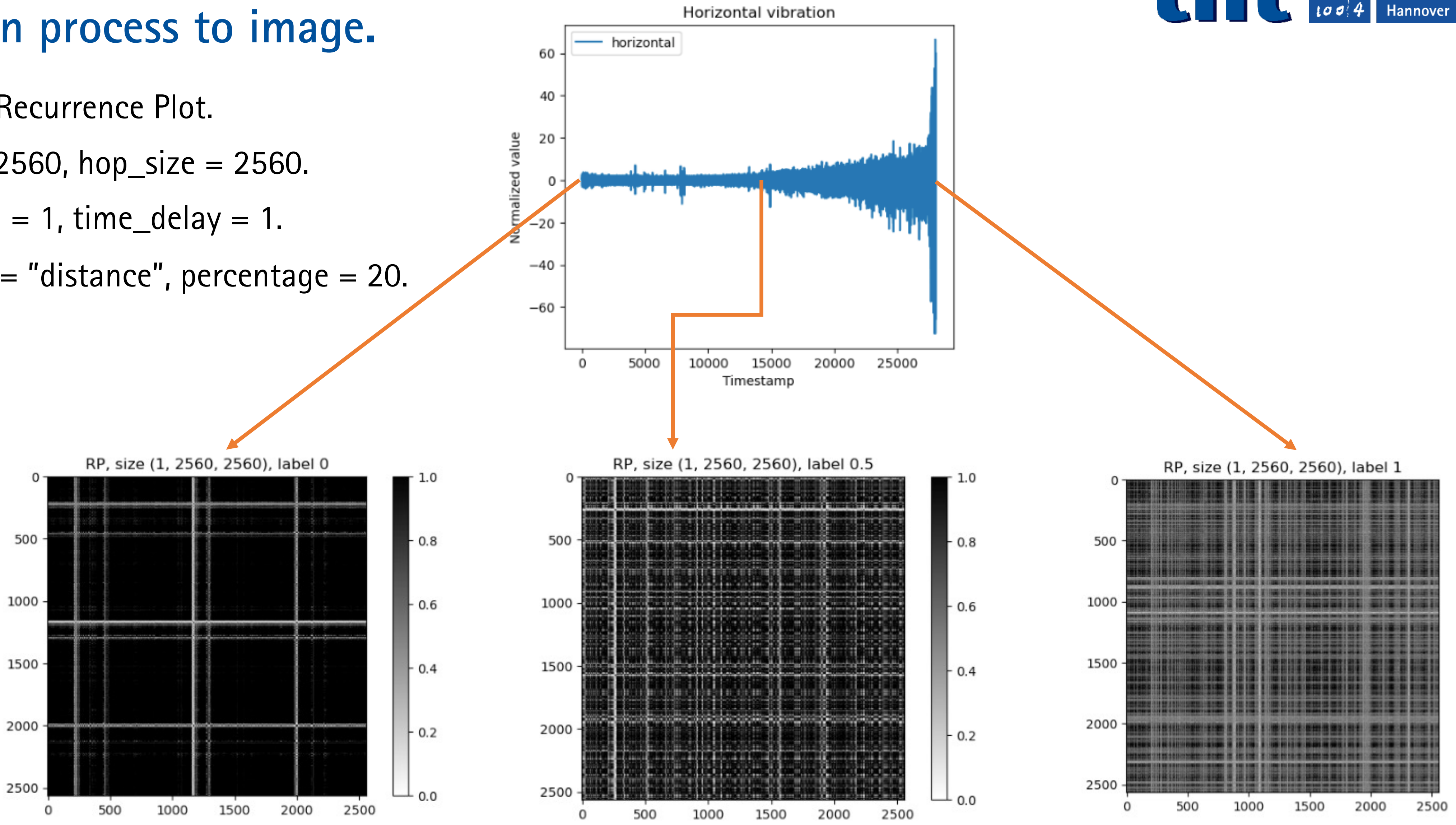

Figure 18: Example RP.

Conversion process to image.

- Example: Mel Spectrogram
- w_size = 25600, hop_size = 2560
- w_stft = 2560 and h_size = 256
- n_mels = 256

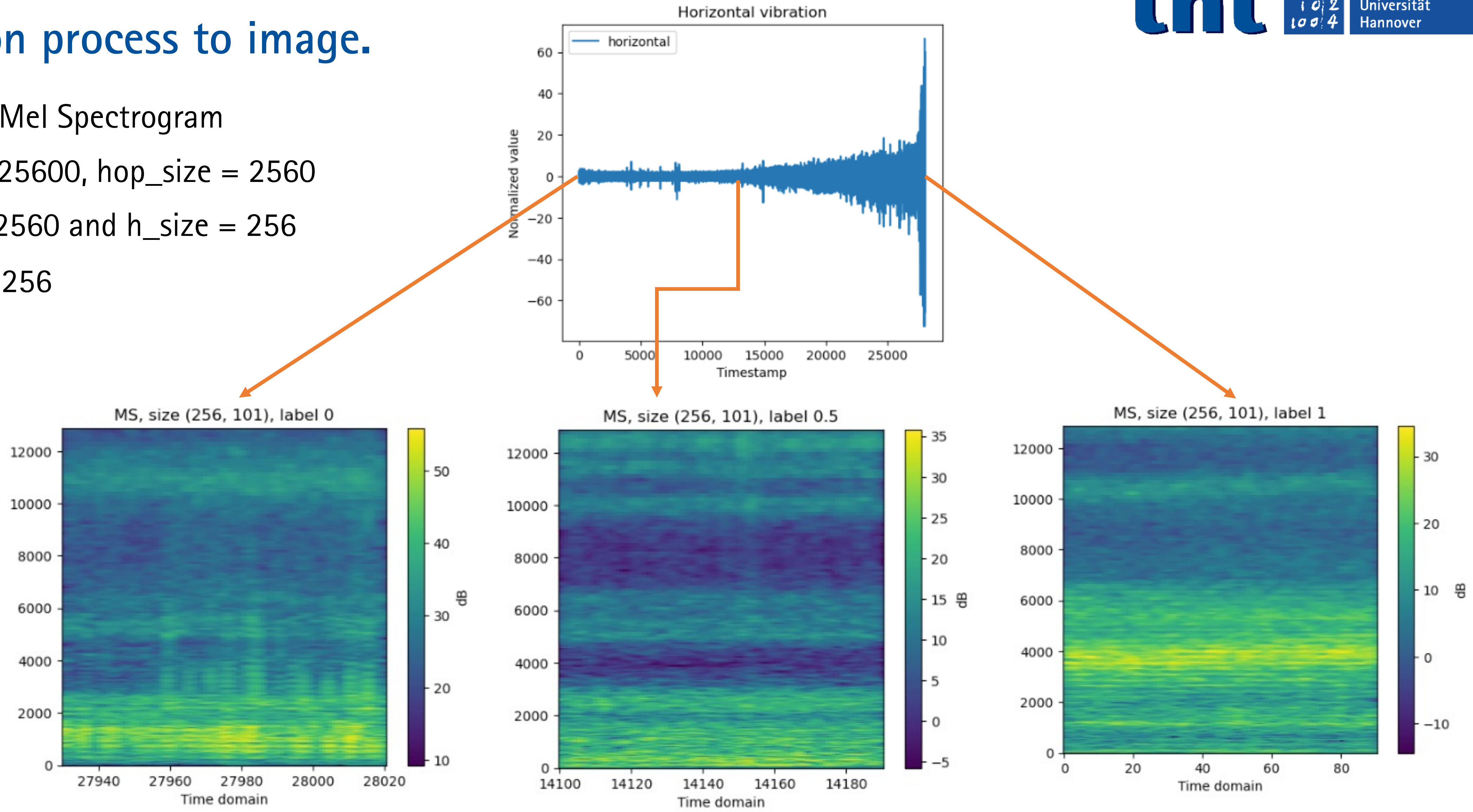

Figure 19: Example MS

Conversion process to image.

- Example: Continuous Wavelet Transform
- wavelet = “cmor1.5-1”
- min_scale = 2
- max_scale = 20
- n_scales = 250

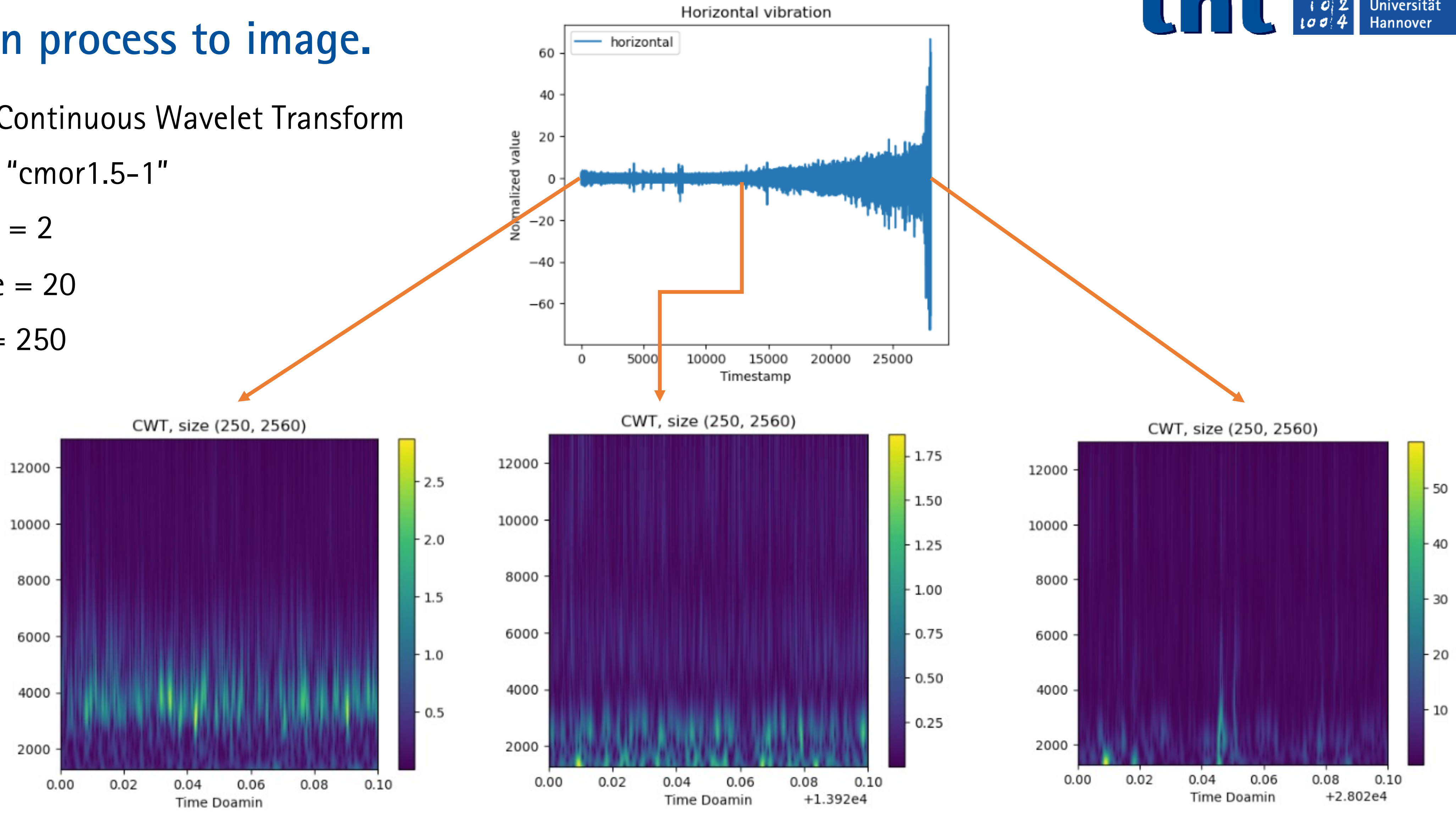

Figure 20: Example CWT

Conversion process to image.

- Example: Markov Transition Field
- strategy = "quantile"
- n_bins = 5

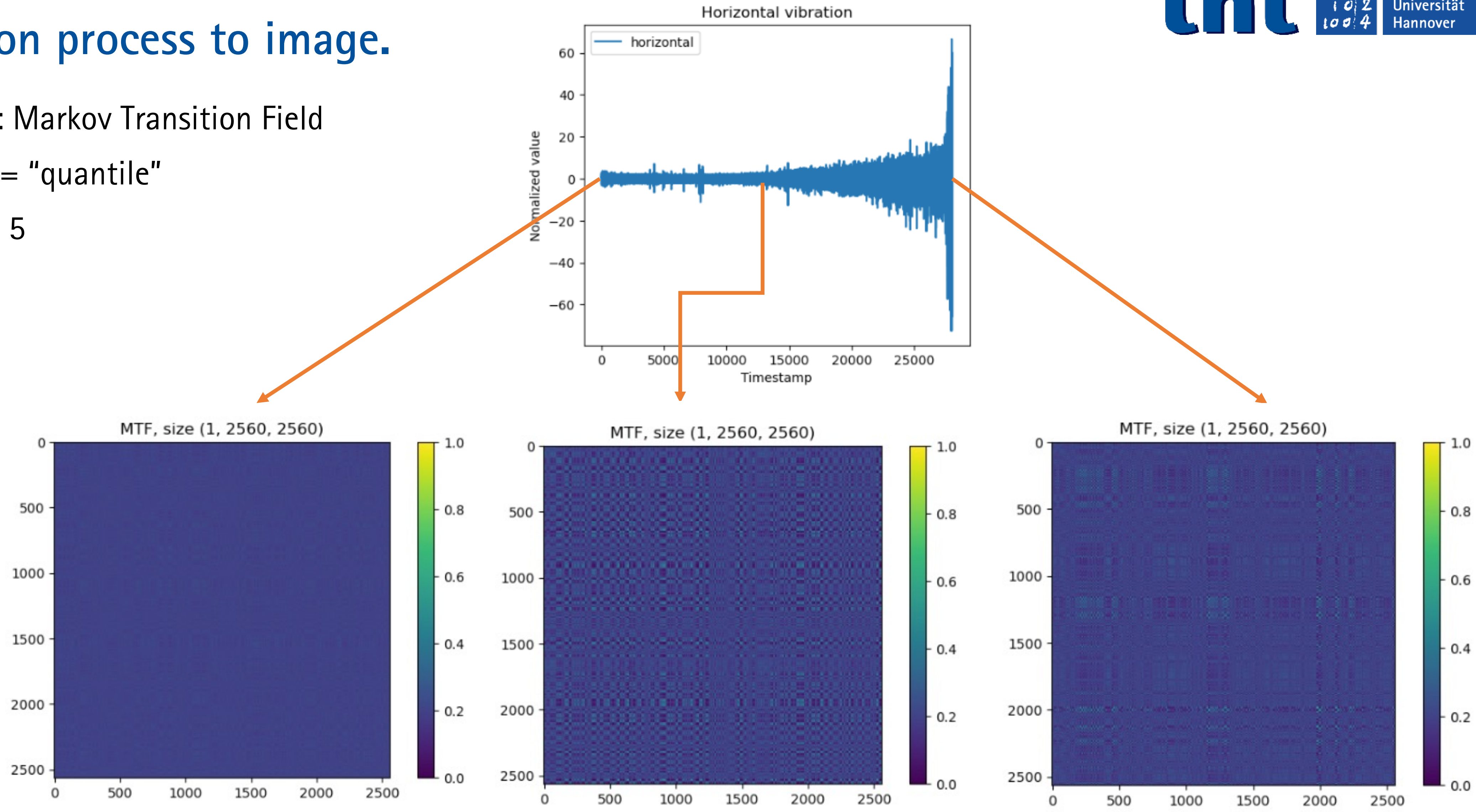

Figure 21: Example MTF