Automatic Classification of Crispiness: Integration of Mechanical and Acoustical Sensor Data

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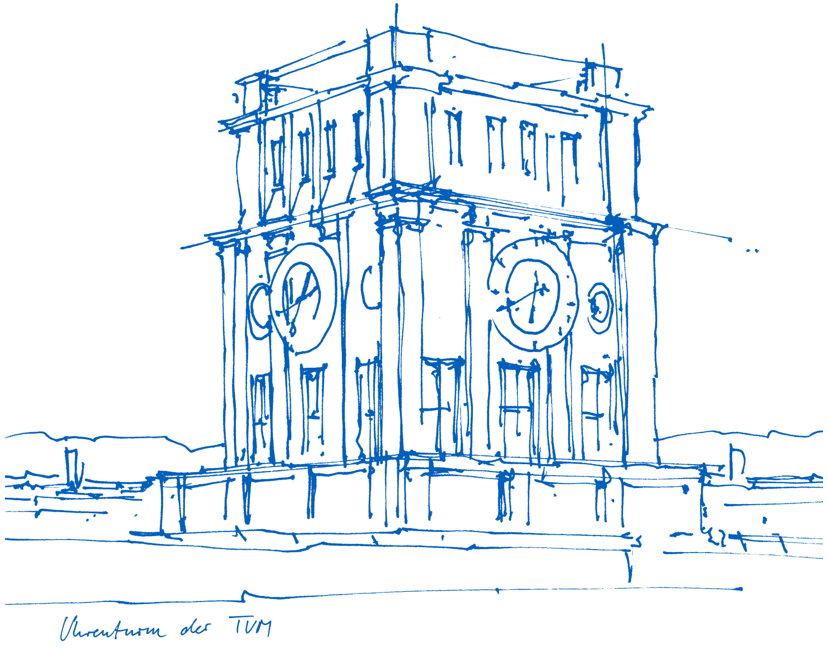
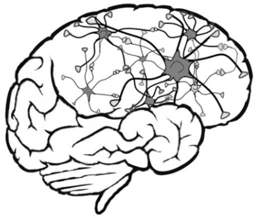
Chair of Process Systems Engineering



MATLAB Expo

Munich, 27. June 2017

The challenge for crispy snacks



Multimodal integration of sensory receptor impulses

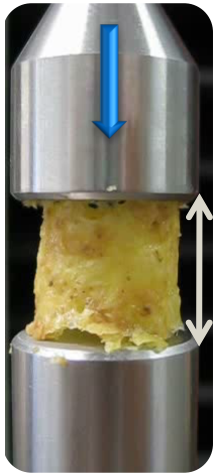
Bourne 2002; Saeleaw & Schleining 2011; Van Vliet & Primo-Martín 2011
soberingthoughts.info; thenounproject.com; www.clipartbest.com; www.iconfinder.com

Overview

1) Instrumental sounds → crisps freshness distinction by humans?
2) Multimodal texture characterization → improved accuracy of crisps freshness classification?
3) Spectral features vs. traditional temporal features → impact on classification?

Corn starch extrudates

Humidification



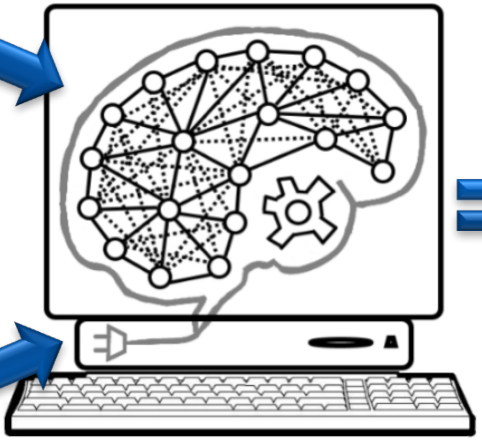
1 cm

Crushing

Human senses

+

Instru-mental sensors



MATLAB algorithms & models

=

Freshness level

Multimodal data aquisition

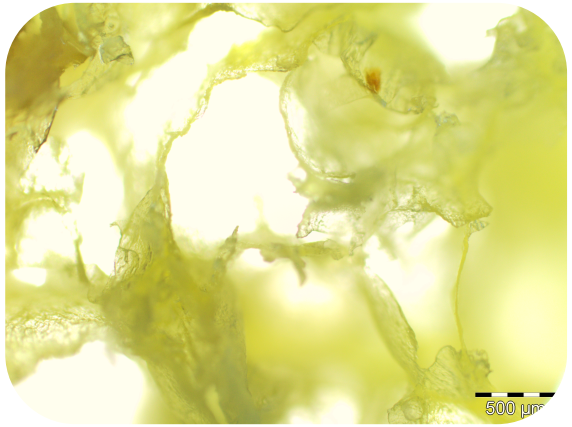
1 Instrumental analysis

~100 / sample type → Mechanical measurement → Acoustical recording

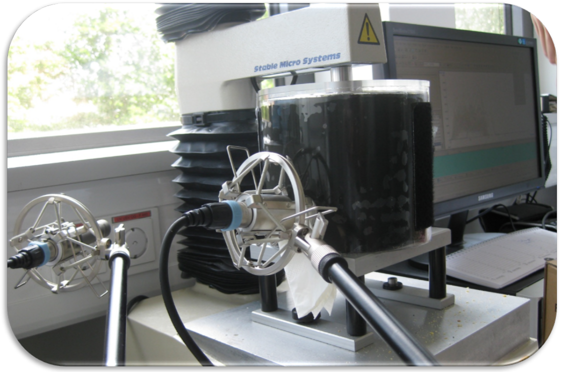
2 Sensory analysis

Trained panel (>16) → Hedonic panel (78)

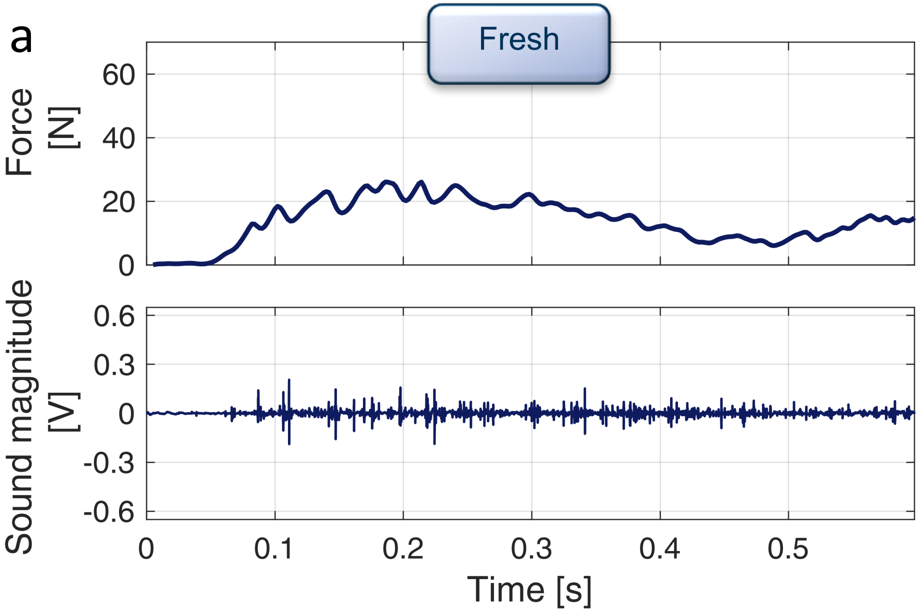
Significant sound characteristics | Consumer preferences | Expert knowledge

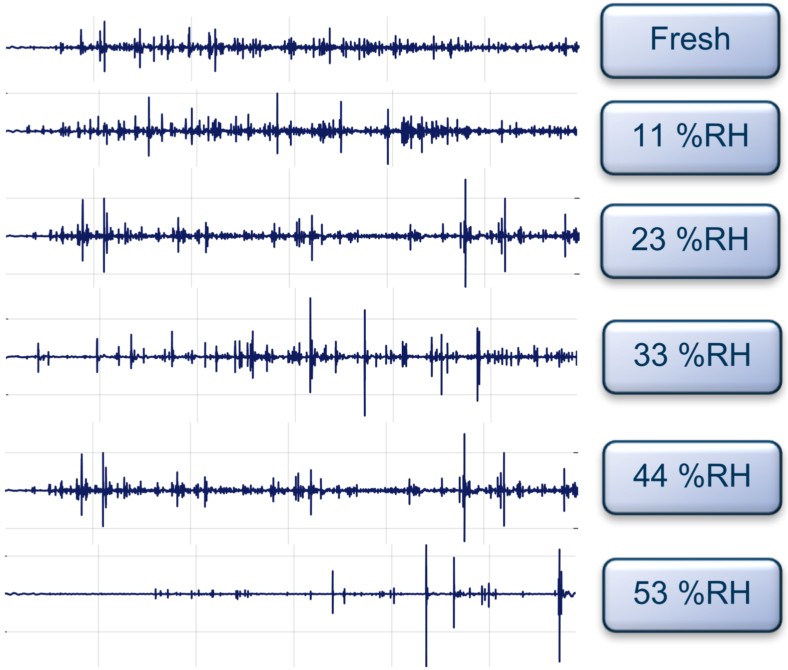


Light microscopy [500µm bar]



Compression test + sound recording





Automatic classification strategy

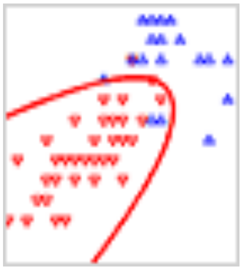
Feature extraction

- Time domain
- Frequency domain

Feature selection / reduction

- Significant parameters
- Complexity reduction

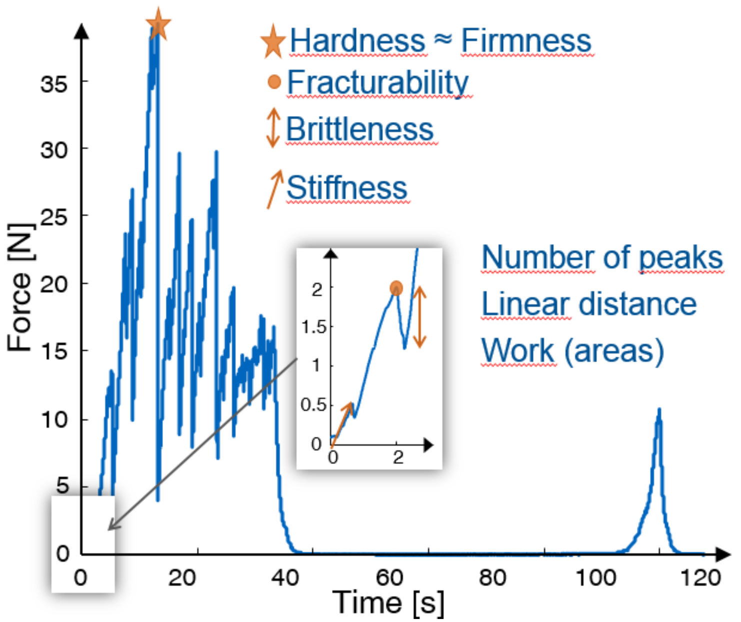
Model training, validation & testing



Temporal vs. Spectral analysis

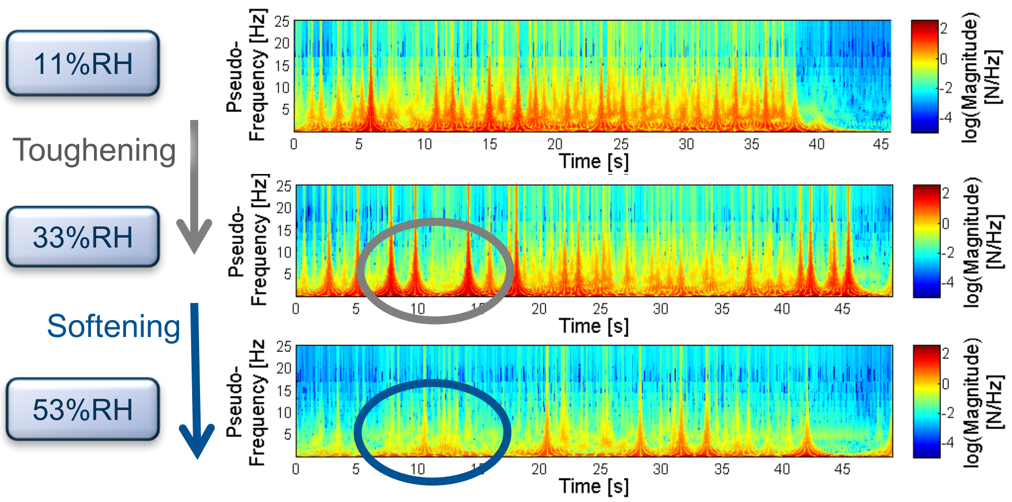
70 features:

Time domain

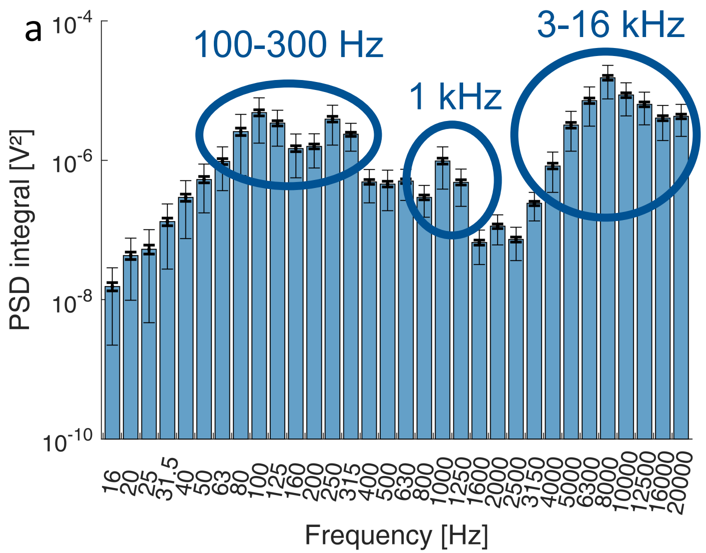


→ No reproducible & reliable prediction of crispiness using single texture parameters

Frequency domain



→ STFT, CWT & HHT suitable for irregular multi-fracture phenomena



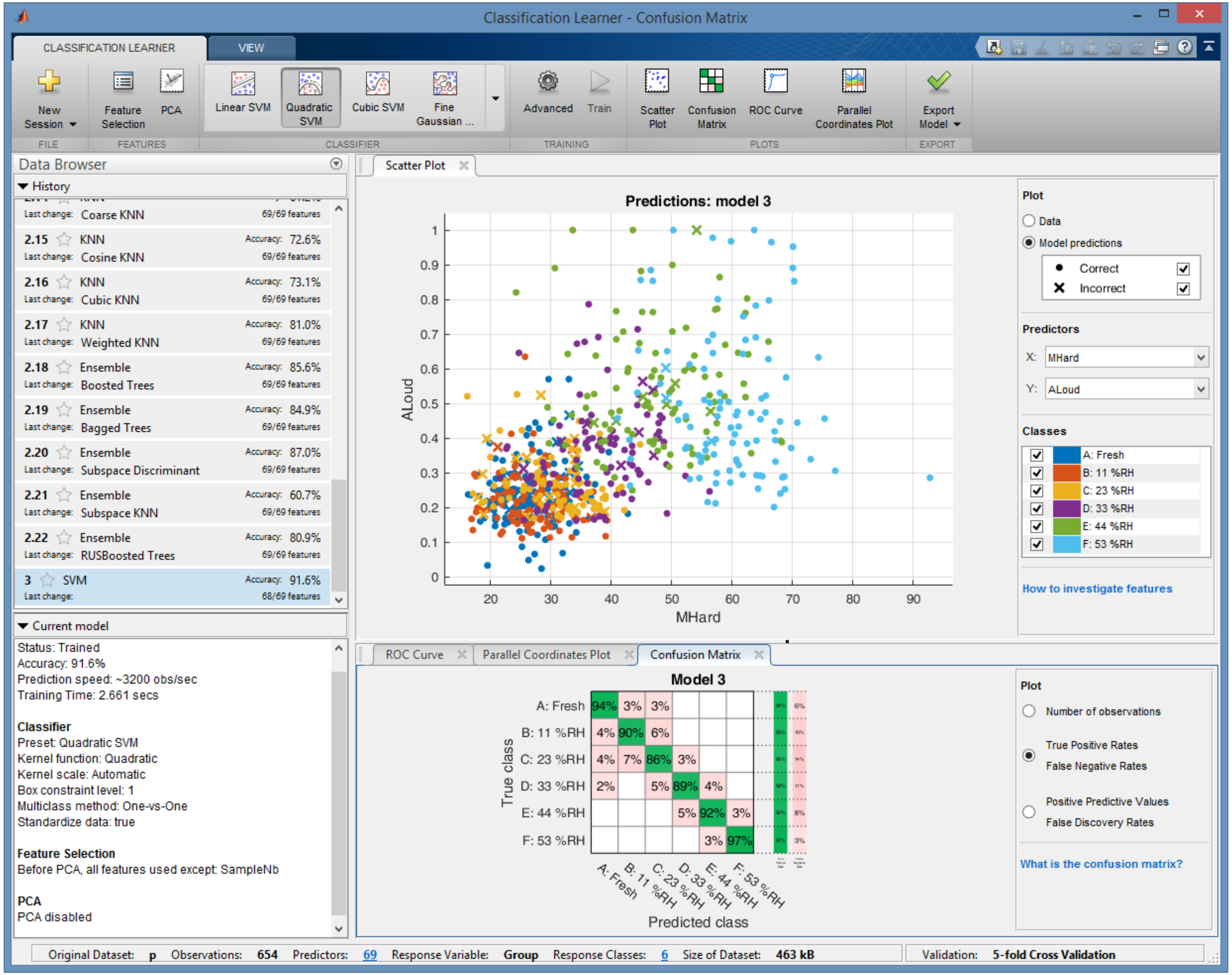
→ Fourier spectrum in octaves suitable for classification

Sanahuja & Briesen, 2015

Classification Learner App

Algorithms screening:

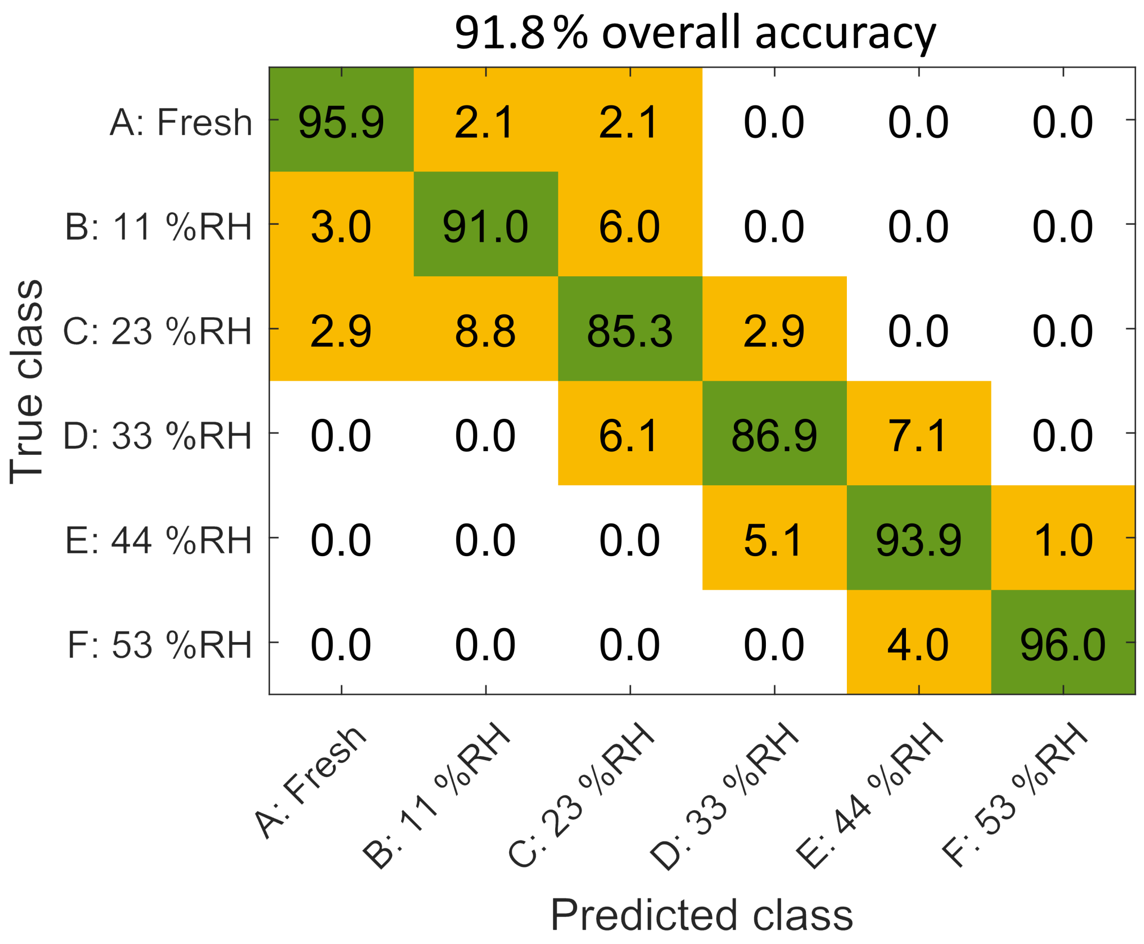
- Decision trees
- Discriminant analysis
- Nearest neighbor
- Ensemble classifiers
- Support vector machines (SVM)
- Artificial neural networks (ANN)



Classification results

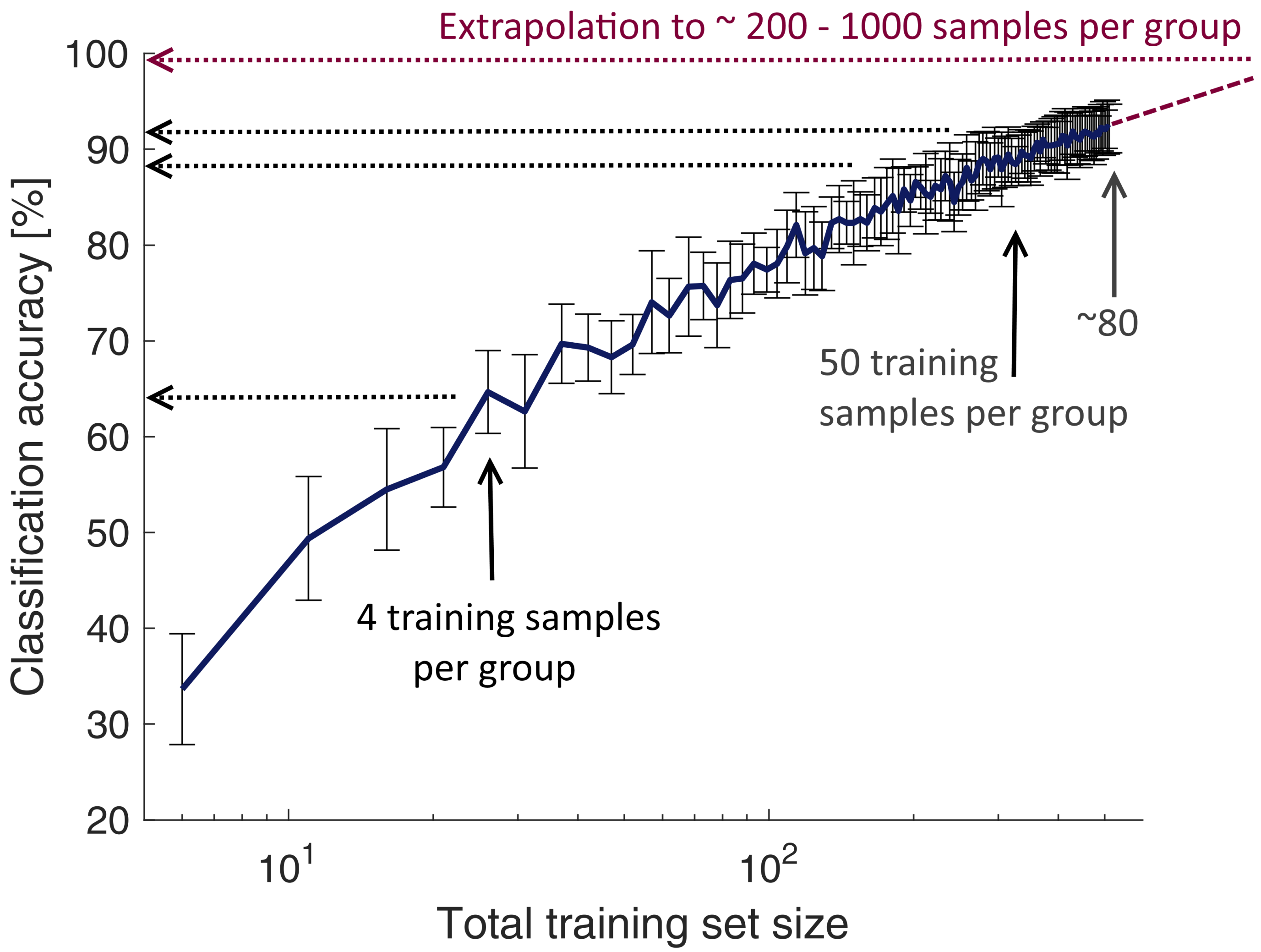
- Non-linear relationships between food physics and freshness
  → mimics psychophysics of sensory integration

- Best predictions using
  - selected temporal
  - third-octave spectral features
  - from mechanics & acoustics



Quadratic SVM: 5-fold cross-validation, 20% test data, measured at 10 mm/s crushing

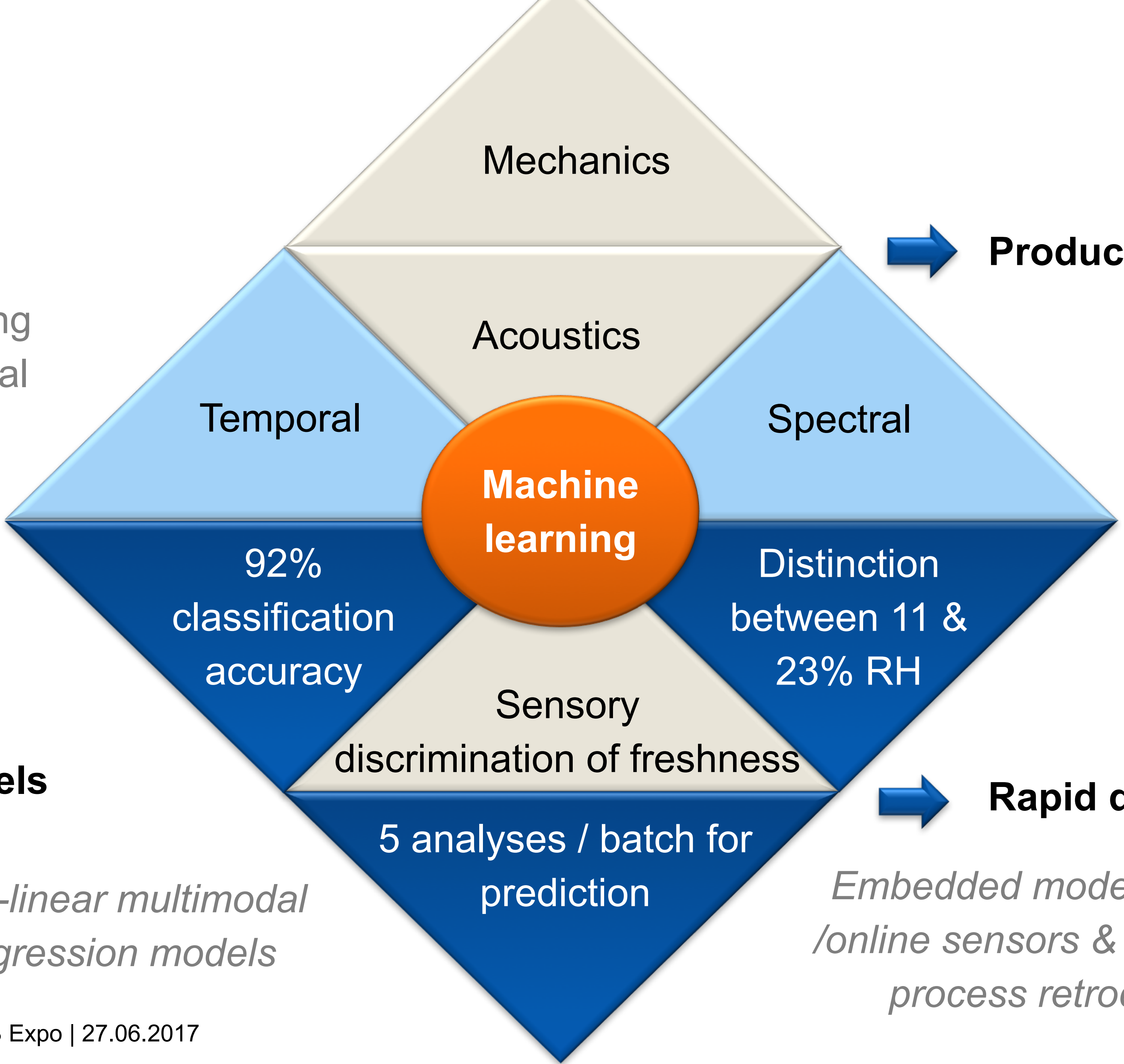
Learning Curve



High potential for improvement using more training data

Conclusion

Impact factors:
loudness, pitch, homogeneity of crushing acoustical & mechanical patterns, toughness, brittleness



→ **Product optimization**

Classification models

Non-linear multimodal regression models

→ **Rapid quality control**

Embedded models with in-/online sensors & production process retrocontrol

Thanks

Fraunhofer
IVV

- Horst-Chrisitan Langowski (institute access)
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- Raffael Osen (TA access + extruder)

TUM Diversity Laura Bassi-award

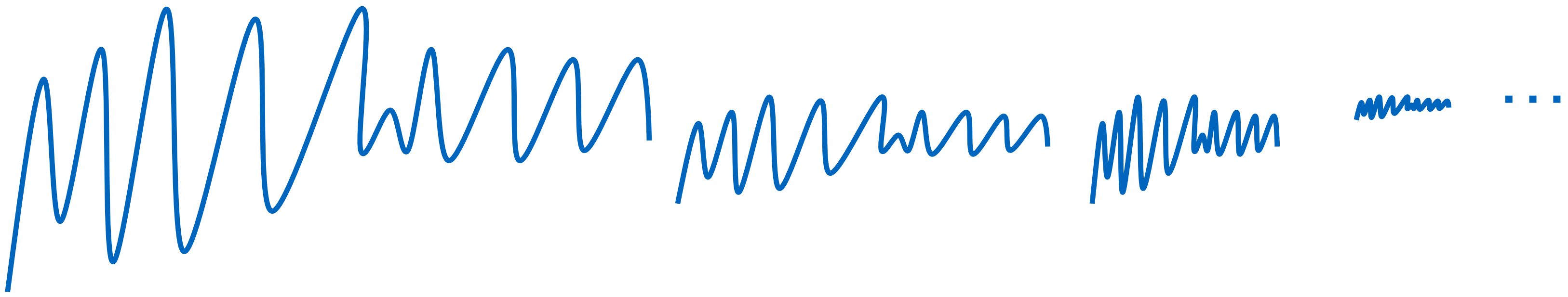
- Hubert Kollmannsberger (sensory)
- Carlotta Ziegltrum, Simone Maurer, Katja Jontes
- Many colleagues (advice, discussion, sensory panel)

www.photoshop-bg.net

Externals

- Henri Braun (EMD)
- Lisa Drobny (Winopal, TA-help)
- Michael Mudra, Uwe Beis (acoustics)

Let‘s ride food science waves!



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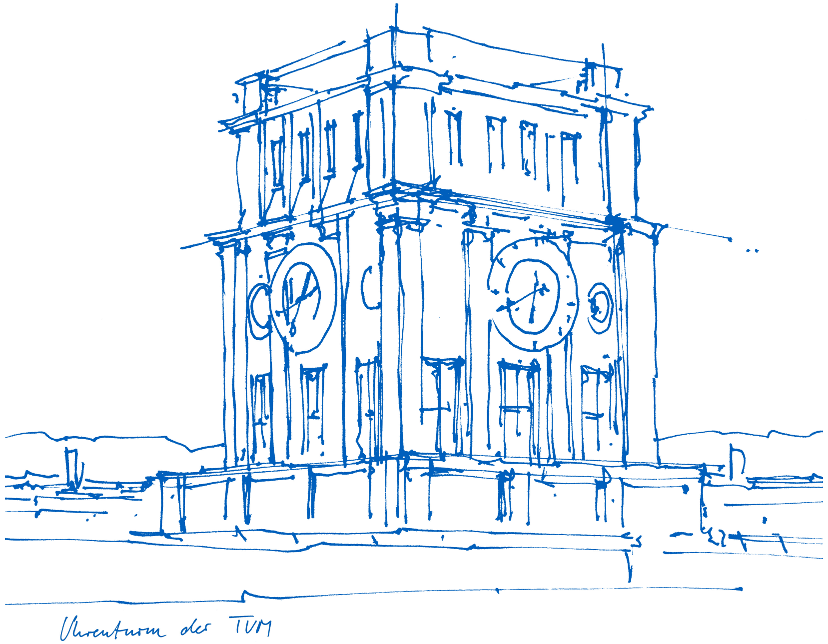

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Backup-slides

- Crispy project timeline
- Sensory freshness classes
- PCA representation
- Automatic classification strategy
- SVM results
- ANN results

Crispy project

Timeline

2014 Prework on mechanical & spectral analyses

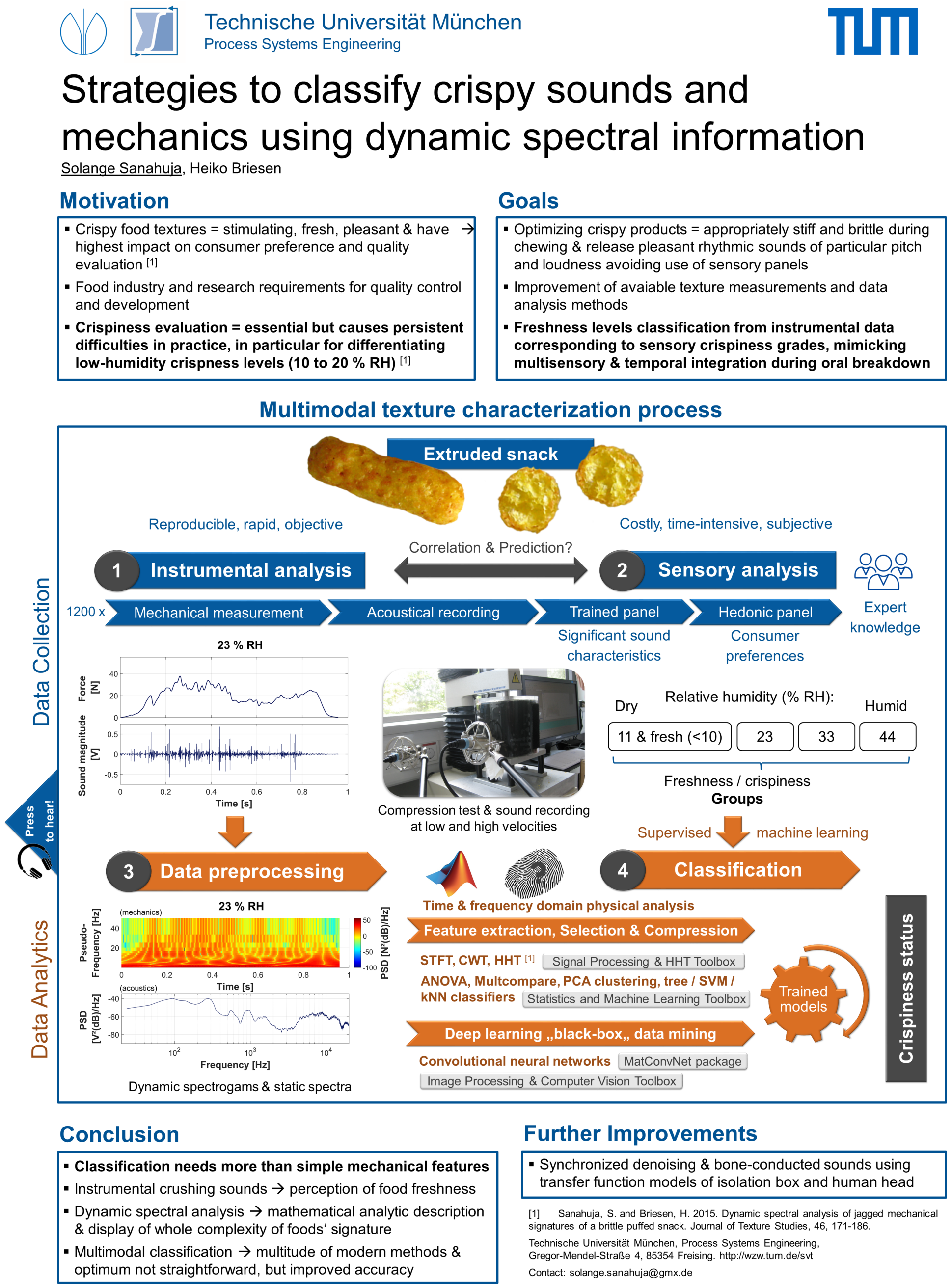
✓ Food Oral Processing Conference:
Dynamic alternatives to fractal and Fourier methods for analysis of crispy / crunchy food products

2015 ✓ Journal of Texture Studies, 46, 171-185:
Dynamic spectral analysis of jagged mechanical signatures of a brittle puffed snack

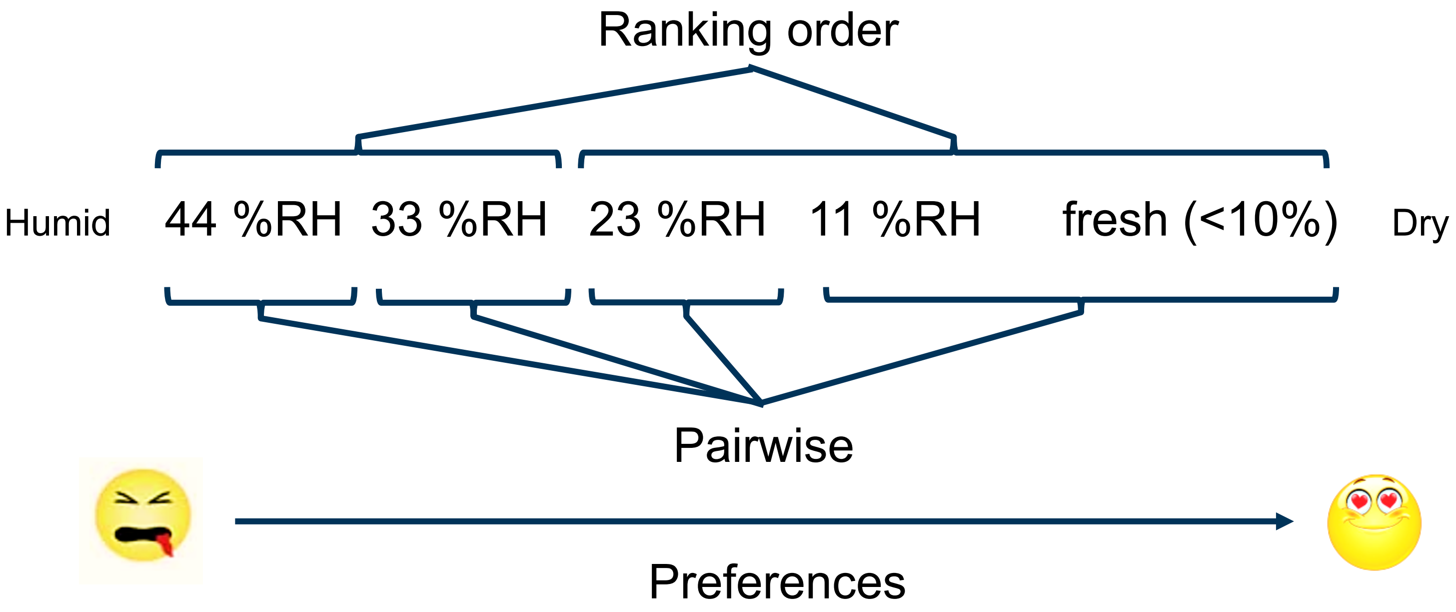
Mechanical, acoustical and sensory data collection

2016 ✓ Modelling & Poster at MATLAB Expo:
Strategies to classify sounds and mechanics using dynamic spectral information

2017 ✓ Submitted paper



Humans perceive & evaluate freshness of chips only based on instrumental texture analysis sound records

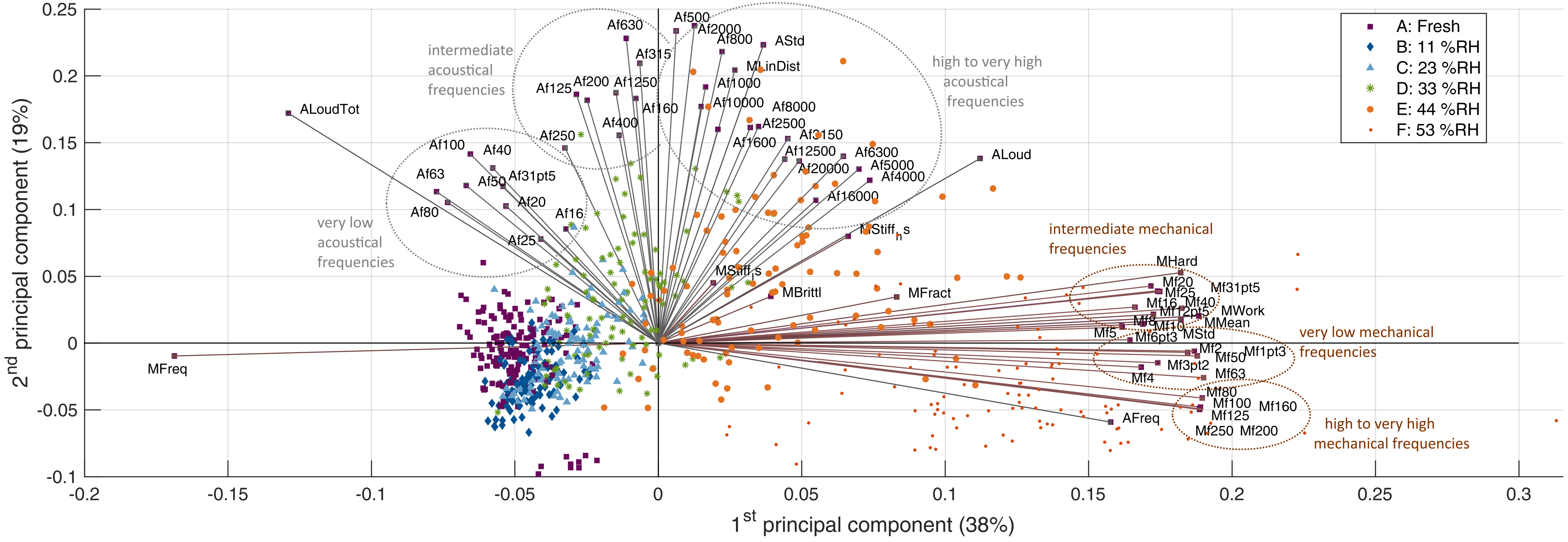


- Significant differences (Friedman-Test, $\alpha = 0.01$) & ranking (Page-Test, $\alpha < 0.05$)
- 2 groups (LSD „Least Significant Difference“)

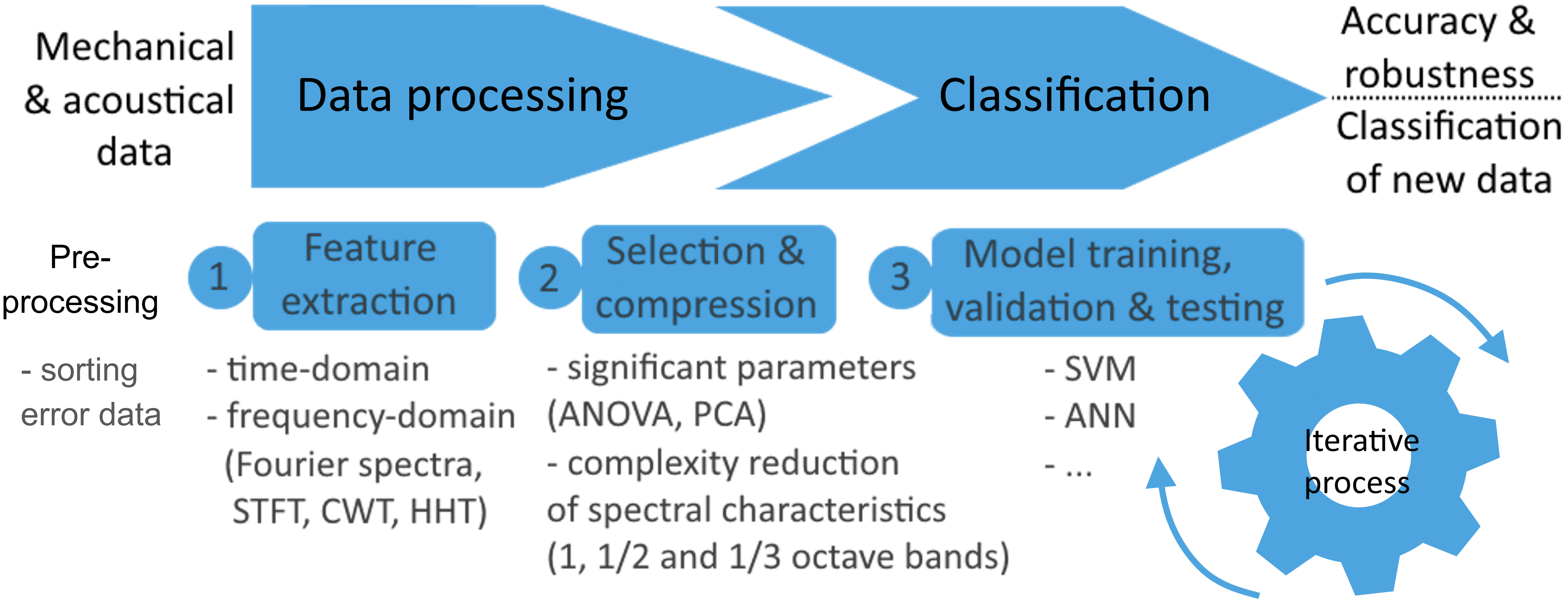
DIN 5495; 8586; 8587; 10950; 10961

Full PCA

Linear relationships not sufficient for modelling psychophysics phenomenon of crispiness sensation



Automatic classification strategy



Classification models & results

Modeling & evaluation

- 10 x 5-fold cross-validation: suited for small datasets
  → average accuracy & variability estimation
- Training/validation with 80%, test with 20% random samples for each sub-model

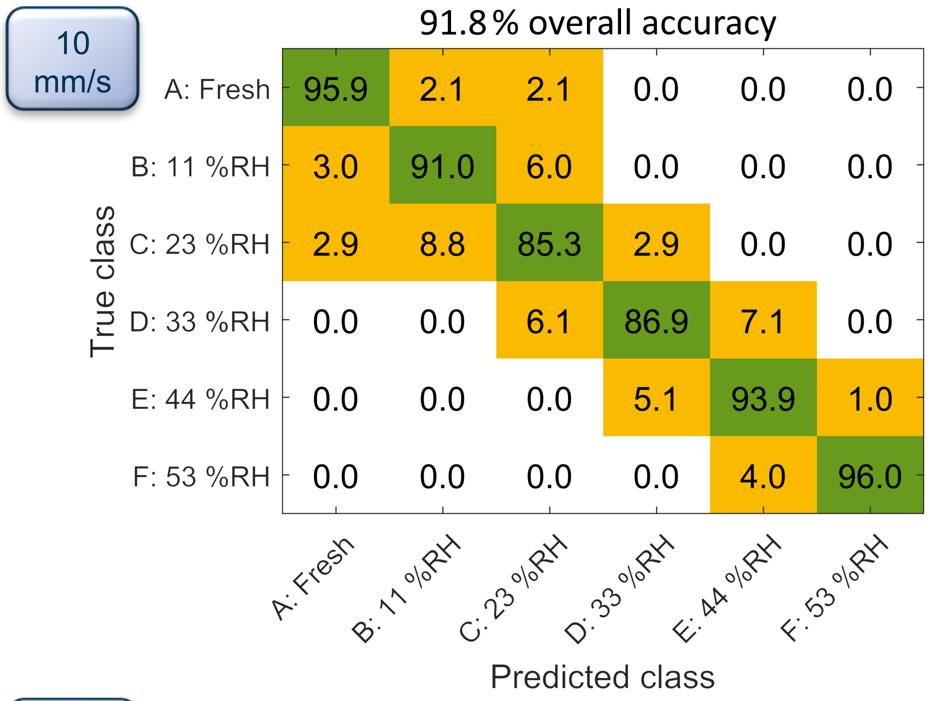
Model selection

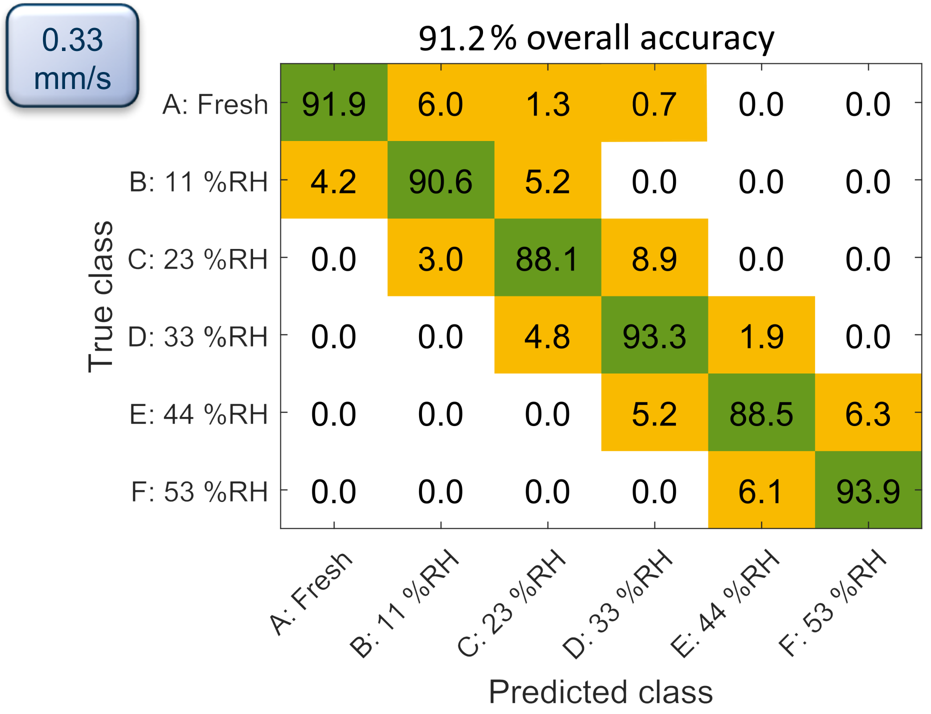
- Psychophysics models: non-linear relationships between food physics and sensory sensation

→ Best models: Quadratic SVM & ANN with disabled PCA preselection (linear)

Results

- Best predictions using selected temporal + third-octave spectral features from mechanics & acoustics
- Crushing velocity: better overall accuracy at 10 mm/s but better distinction between 11 & 23% RH at 0.33 mm/s





ANN results

Confusion matrices

- one of the best ANN models
- 1 layer of 10 hidden neurons
- high-velocity selected temporal combined with third-octave spectral mechanical and acoustical features

Overall accuracies [%] on the test sets:

(a) 1 layer of 10 hidden neurons;
(b) 3 layers of 20 hidden neurons;
(c) 1 layer of 250 hidden neurons.

Domain	Features	Octave bands	Number of features	Test velocity	ANN model		
					(a)	(b)	(c)
Time & Frequency	Combined selected	1/3	68	10 mm/s	85.8±3.8	85.1±4.9	80.9±5.8