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Selective Detection of Indoor VOCs using a Virtual Gas Sensor Array

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Agenda

- Indoor VOCs (Volatile Organic Compounds)
- Temperature cycled operation (TCO) of MOS gas sensors
- TCO optimization
- Data processing
- Sensor lab tests
- Field test sensor systems
- Conclusions

Indoor VOCs

- Some Volatile Organic Compounds are hazardous pollutants in indoor air
- Many of them are carcenogenic

- Target gas concentrations are ppb and sub-ppb level

  → **Very high sensitivity required**
- Benign interfering gases (e.g. Ethanol) can occur in much higher concentrations (ppm range)

  → **Very high selectivity required**
- Key target pollutants in VOC-IDS: Formaldehyde, Benzene, Naphthalene

Gas	WHO guideline [1]		Upcoming regulations in France [2]	
	µg/m³	ppb	µg/m³	ppb
Formaldehyde	100	81.3	10	**8.13**
Benzene	--	--	2	**0.6**
Naphthalene	10	**1.9**	--	--

TCO of MOS gas sensors

- Temperature cyclic operation (TCO) creates a virtual gas sensor array
- A single sensor is operated at different states which changes ist selectivity and sensivity to different gases [3] → Virtual gas sensor array
- Many gas-specific effects occur during and after transition between temperatures (relaxation effects)

- Used sensors are slow but sensitive (types 1000, 2000 and 5000; UST, Germany; thick film ceramic substrate MOS sensors)

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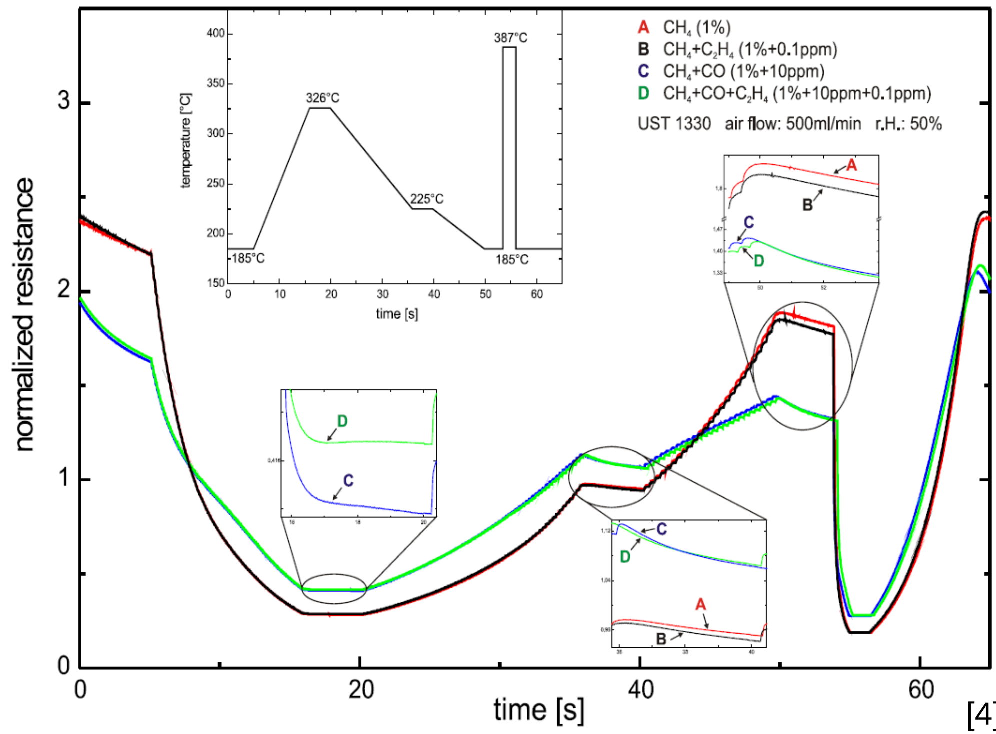
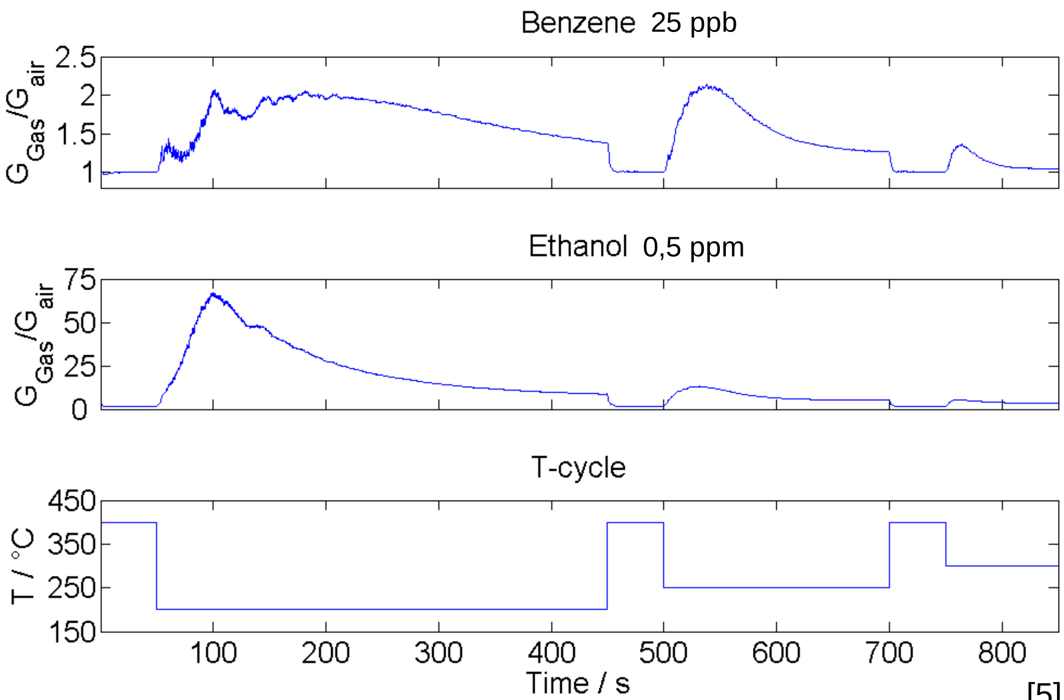


[4]

TCO optimization



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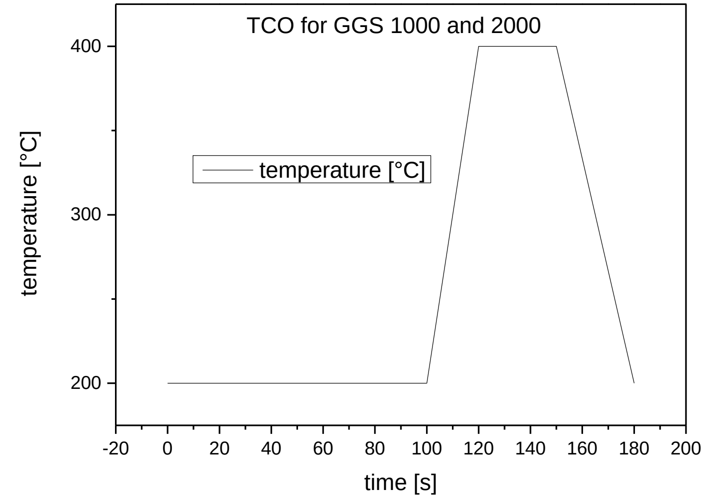
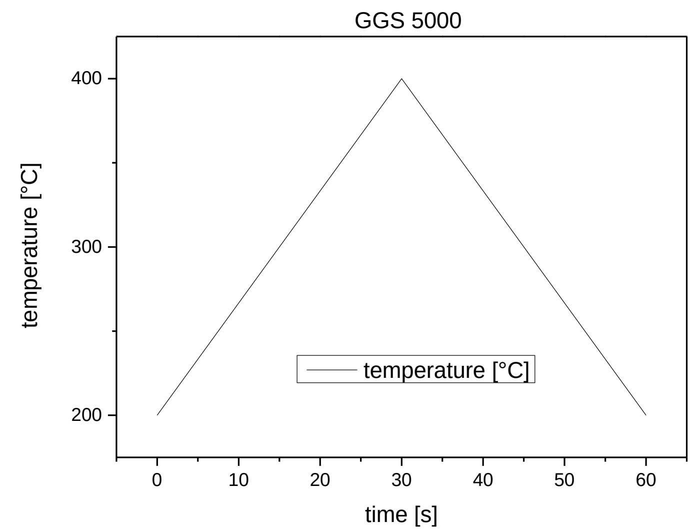




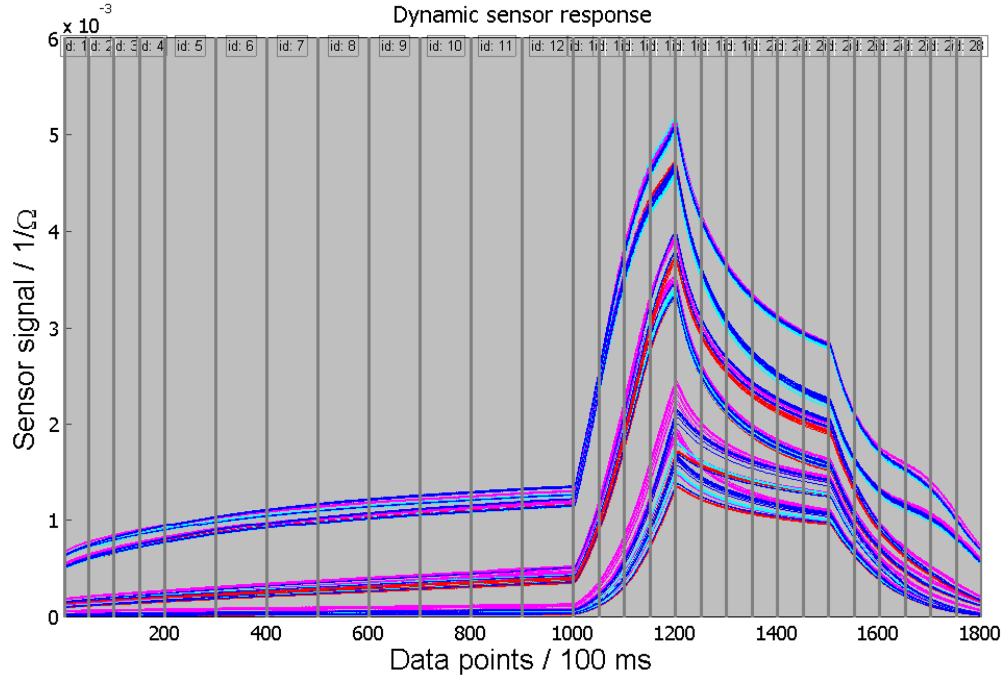
Analysis of sensitivity curves of transitions to different temperatures

Sensitivity peak several seconds after cooldown!

- ➢ **Development of temperature cycles optimized for sensitivity and length**

Data processing

- Feature extraction for each section of each cycle
  - Mean value
  - Best fit line (slope)
  - (others possible)



- Linear discriminant analysis (LDA)
  - ➢ Pattern recognition using the extracted features
  - ➢ Here: classification of different gases, different concentrations of the same gas are merged into one group

Sensor lab tests

- Target gas concentrations according to (future) guideline values
- Low and high concentration of each target VOC; scenario ventilation control
- Two gas humidities
- Ethanol as interfering gas in comparatively high concentrations

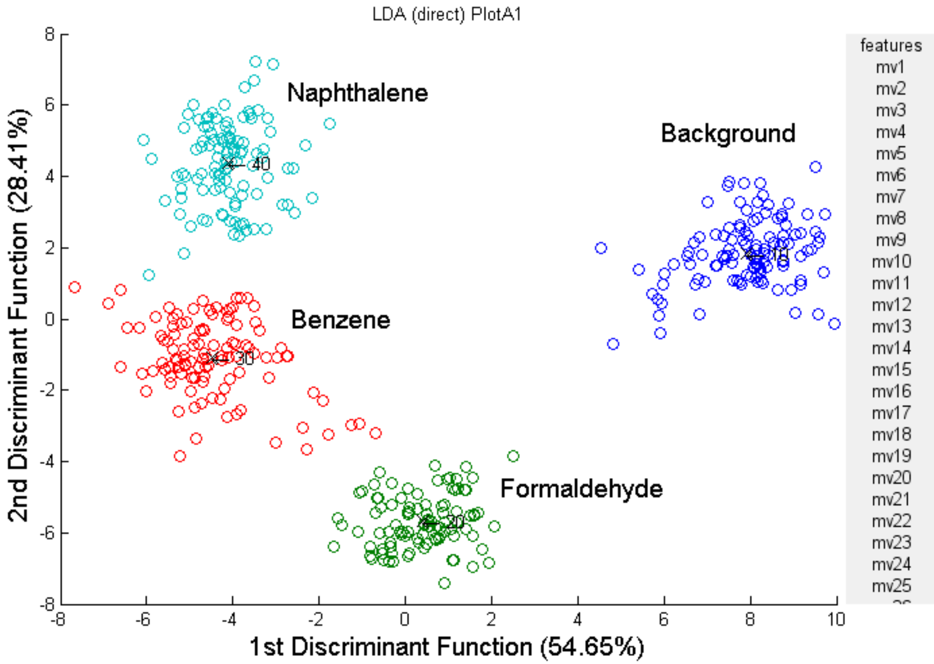
Target gas	Concentration (ppb)	Humidity	Interferents (EtOH ppm)
Air	NA	40%, 60%	none, 0.4, 2
Formaldehyde	10, 100	40%, 60%	none, 0.4, 2
Benzene	0.5, 4.7	40%, 60%	none, 0.4, 2
Naphthalene	2, 20	40%, 60%	none, 0.4, 2

Green: No increased ventilation recommended
Blue: Increased ventilation recommended
Red: Increased ventilation required

Sensor lab tests

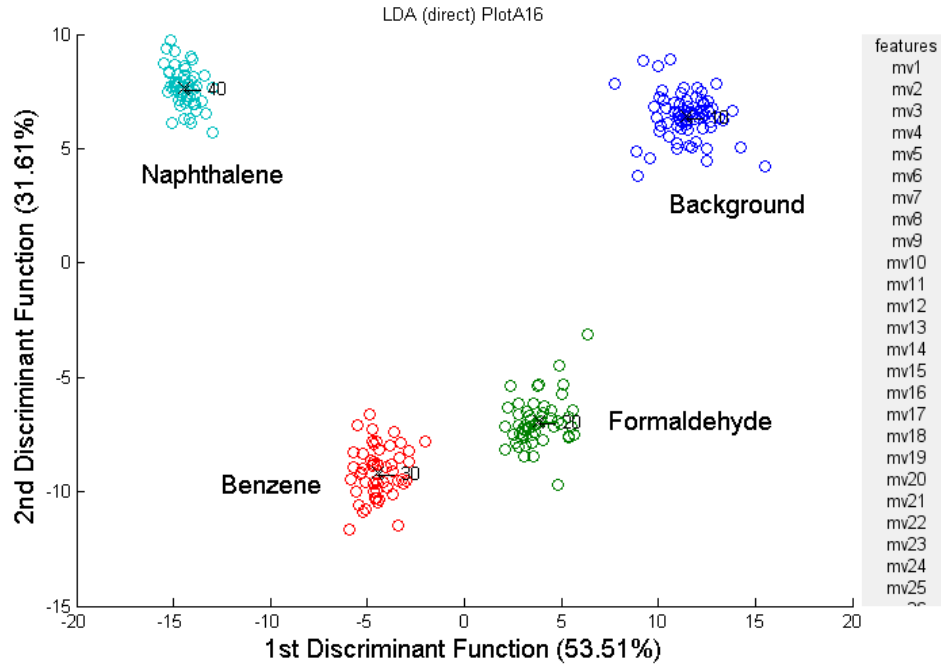
UST type 1000 sensor

Both humidities



Discrimination of different groups / gases possible, little overlap

40 % humidity only



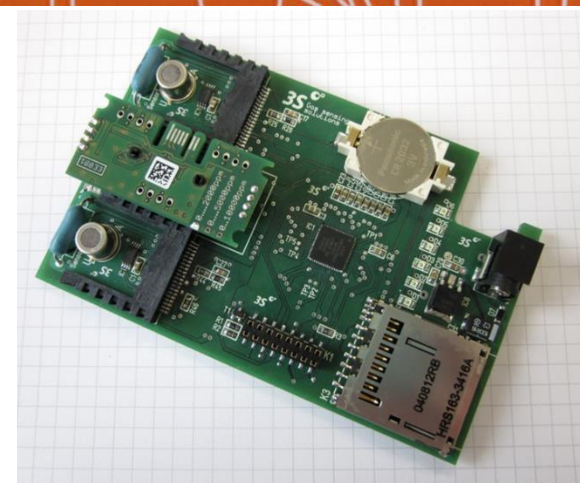
Discrimination improved, no more overlap of groups

- **LDA in several steps might be good approach**
- **LDA training sets for different humidities, measurement of gas humidity**

Field test sensor systems

- Stand-alone field test systems by 3S GmbH (Saarbrücken, Germany)
- 2 MOS gas sensors (+ CO_2 + humidity) with independent temperature control
- Data storage on SD card

- Same test gas profile as for sensors



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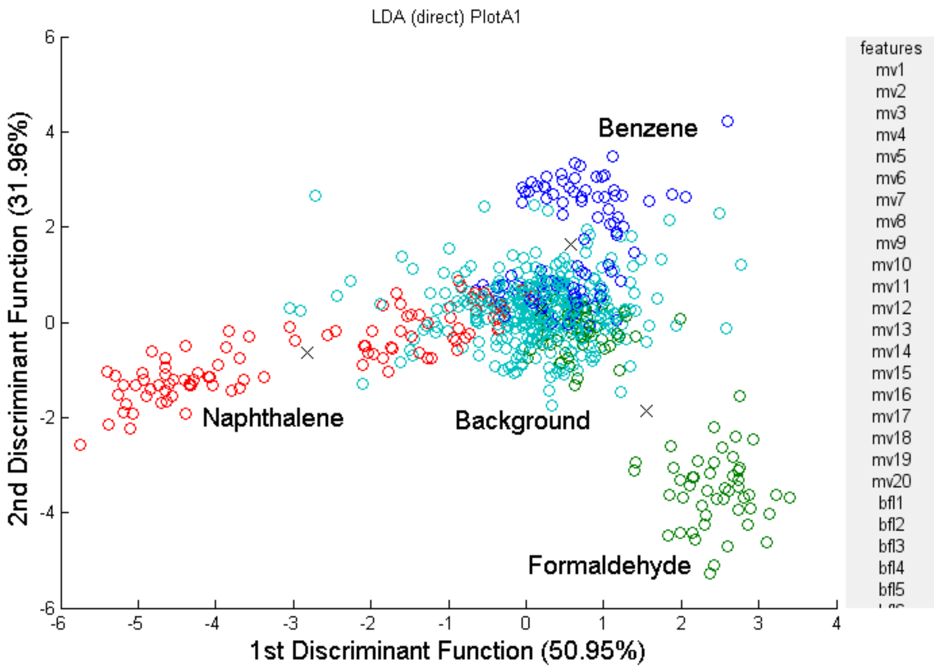
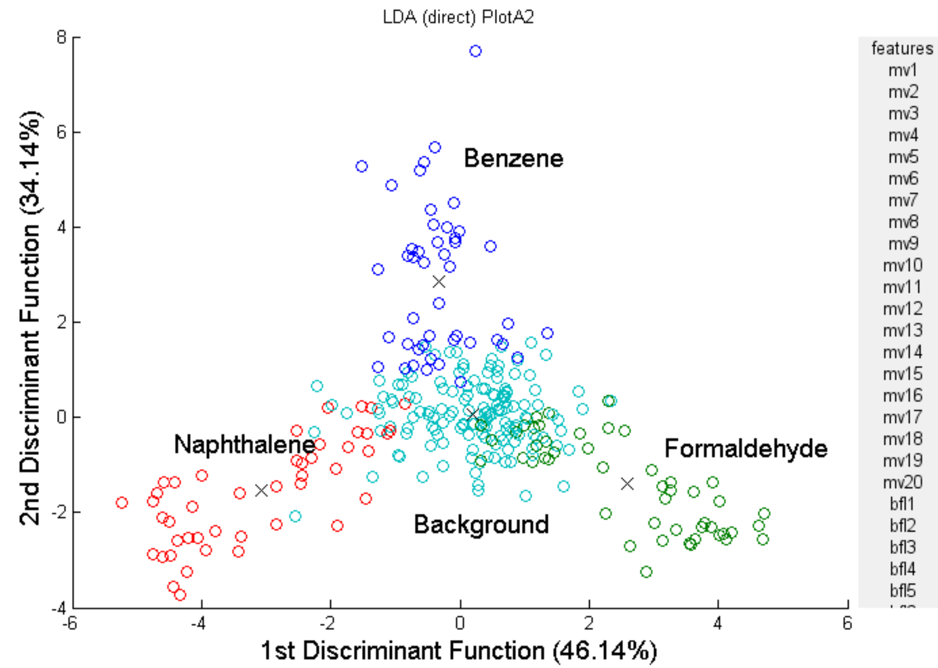
Field test sensor systems

UST type 1000 sensor

Both humidities



40 % humidity only



Discrimination much less effective compared to sensor lab tests
Problematic especially for low VOC concentrations

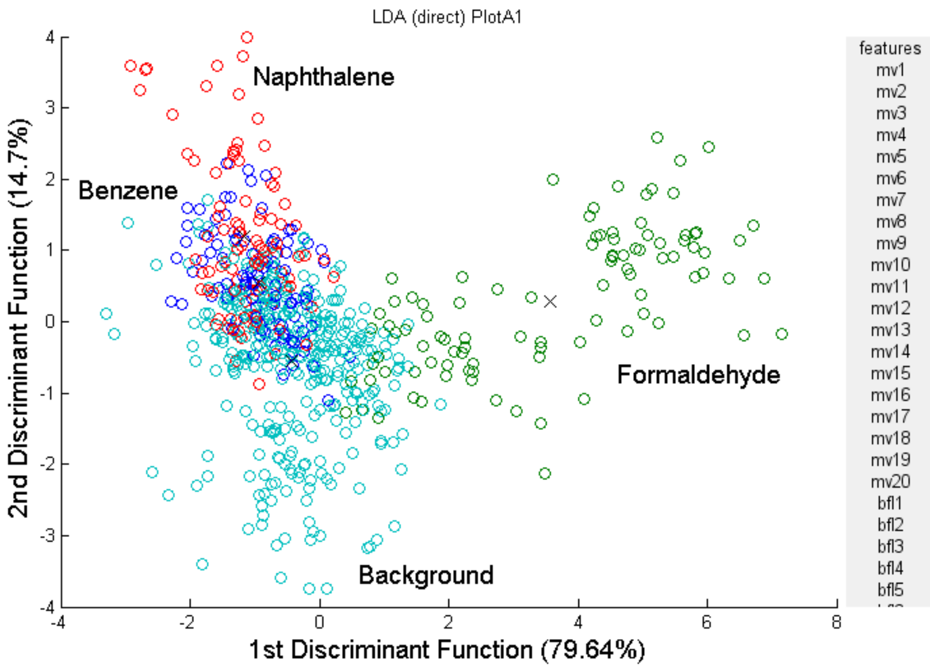
Discrimination improved slightly, especially for benzene

Reason for bad detection compared to measurements of sensors only: Gas emissions of system hardware (Housing, circuit board)! Verified by GC/MS measurements

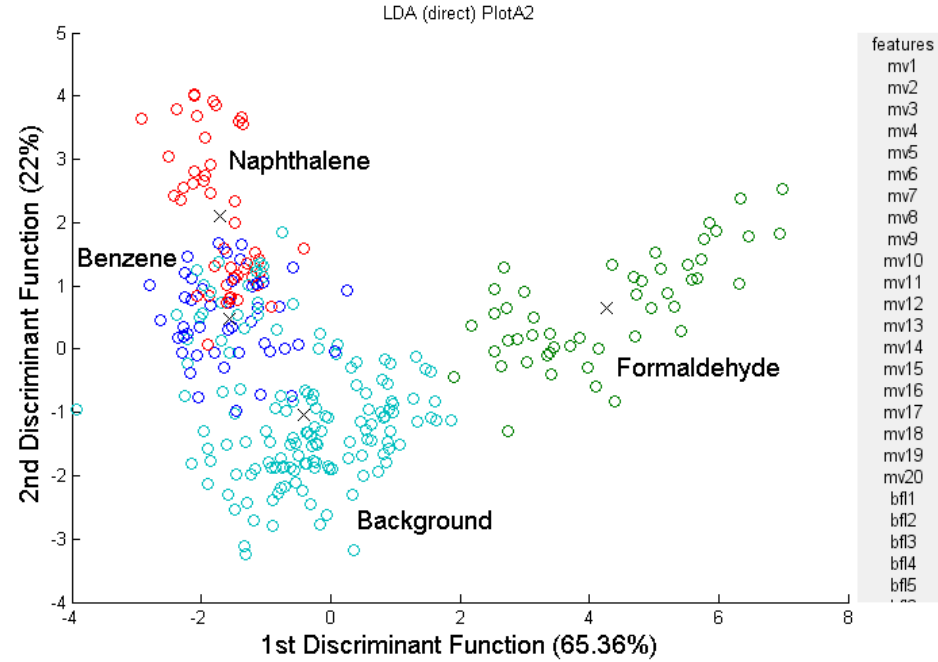
Field test sensor systems

UST type 2000 sensor

Both humidities



40 % humidity only



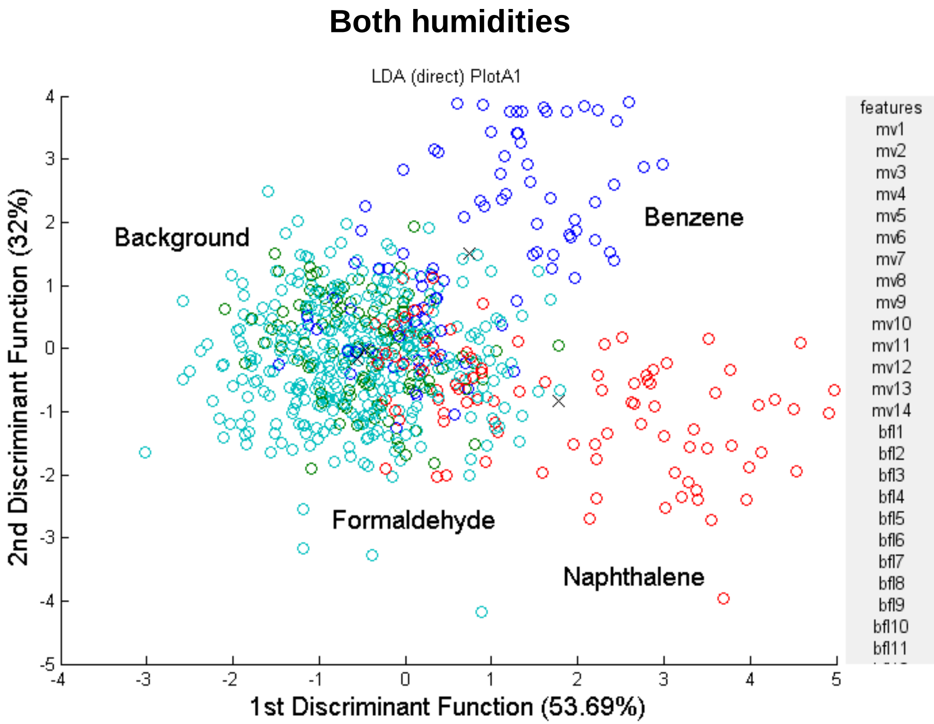
Discrimination of benzene and naphthalene not as good as with type 1000 sensor
Better separation of formaldehyde

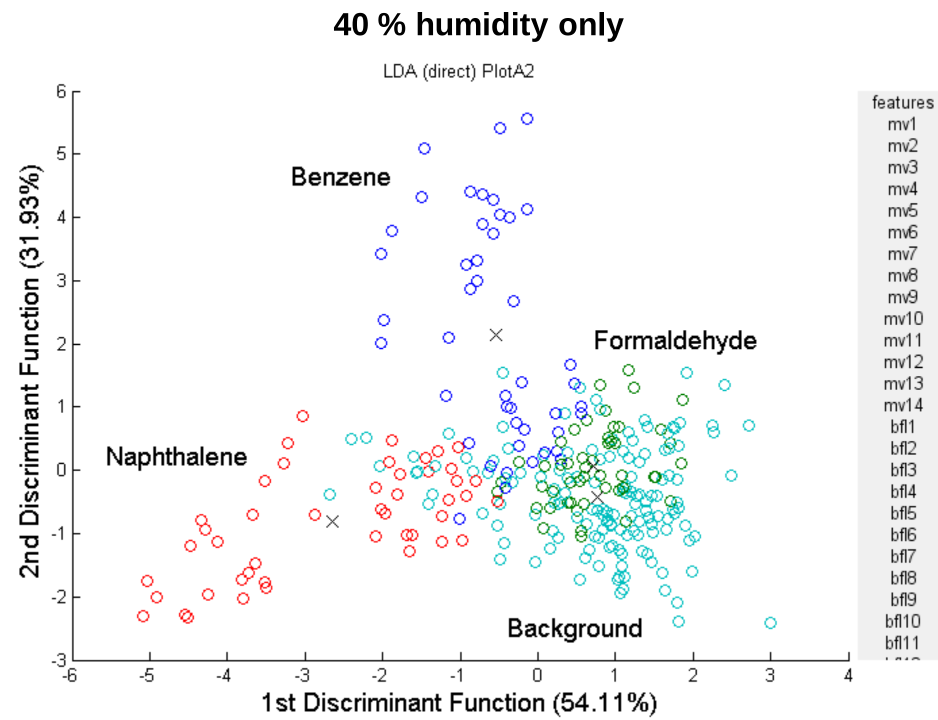
Discrimination improved, especially for formaldehyde

Identification of 10 ppb formaldehyde possible with this sensor

Field test sensor systems

UST type 5000 sensor





Discrimination of benzene better than with the other sensor types
Good separation of high concentration naphthalene

Discrimination improved for benzene and naphthalene, high concentrations

Detection of formaldehyde not possible

Conclusions

- **Detection of ppb-levels of VOCs against much greater interfering gas background possible with MOS gas sensors**

- Optimized temperature cyclic sensor operation and LDA pattern recognition seems to be a promising approach

- Integration of sensors into stand-alone sensor systems is challenging because of gas emissions of the system hardware
  - ➢ Possible improvement of emissions by heat treatments of the systems

- Combined signal evaluation of the different sensor types will be implemented

Acknowledgement

GEFÖRDERT VOM

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mnt-era.net

Project VOC-IDS

16SV5480K

Thank you for your attention!

References

[1] "WHO Guidelines for Indoor Air Quality: Selected Pollutants", Geneva: World Health Organization; 2010

[2] French decree no. 2011-1727

[3] M. Schüler, N. Helwig, G. Ventura, A. Schütze and T. Sauerwald, "Detecting Trace-Level Concentrations of Volatile Organic Compounds with Metal Oxide Gas Sensors", Lecture 7488, IEEE Sensors Conference 2013; Baltimore, MD, USA, Nov. 03 - 06, 2013

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[5] T. Fricke, T. Conrad, T. Sauerwald and A. Schütze, "Progress towards an Automatic T-Cycle Optimization Utilizing an Integrated Gas Sensor Testing and Evaluation Toolbox", IMCS 2014, Buenos Aires, Argentina, 16-19 Mar. 2014