Predictive Analytics

Condition Monitoring & Entry to Predictive Maintenance

Improving defect recognition
with minimal sensorics

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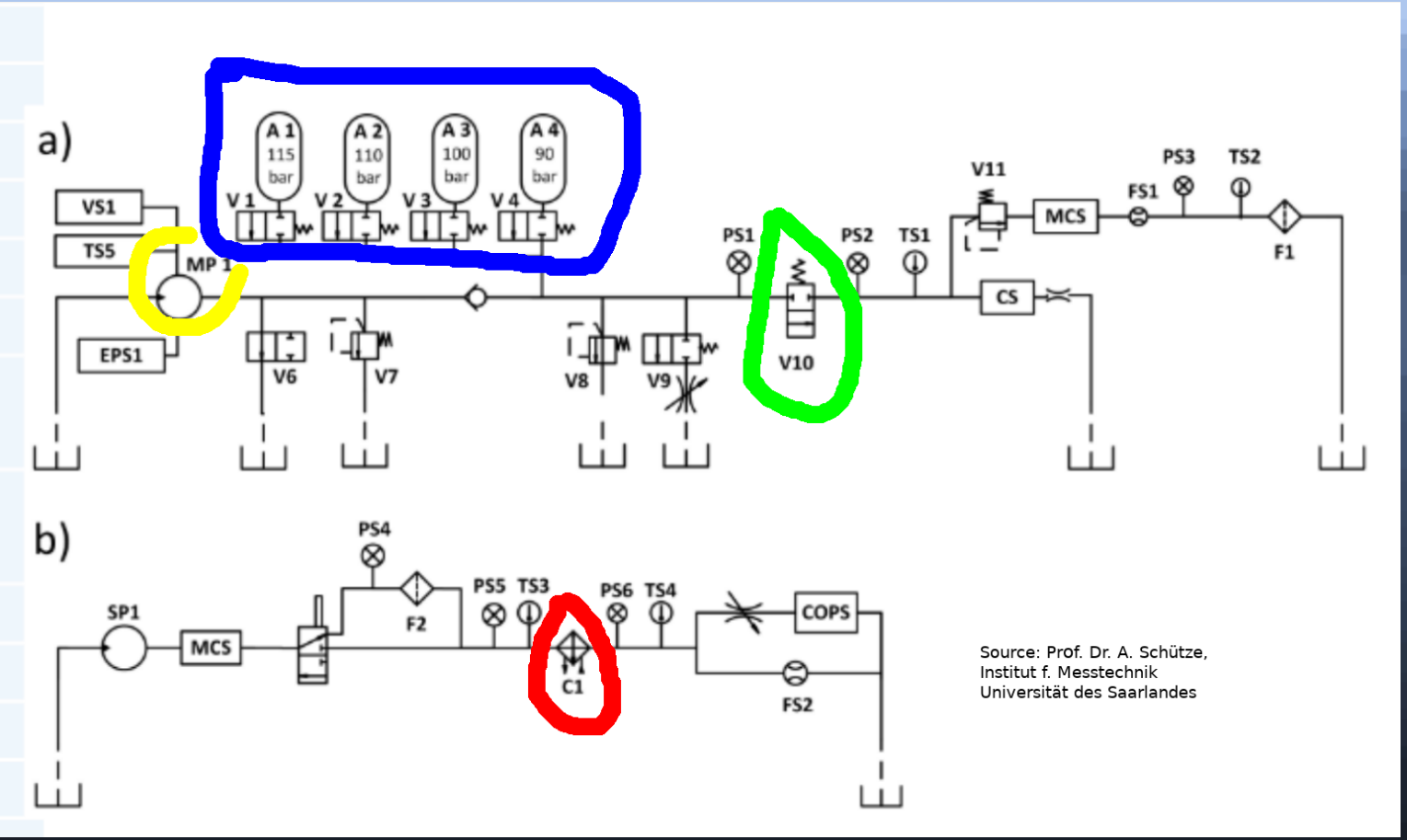
Condition Monitoring

Demo Example

- hydraulic system
- published experimental data by *University of Saarland & Center for Mechatronics and Automation, Saarbrücken*
- independent analysis by Otmar Mak

Automic monitoring



Source: Schütze et al[2017], S. 13

Demo: hydaulic system with work loop and cooling loop

Condition Monitoring

Critical Components

- Cooler (efficiency degradatio)
- main valve (impeded spool)
- Pump (internal leakage)
- Accumulator (precharge pressure loss)

Demo: hydraulic system with 17 sensors

Condition Monitoring

Hydraulic system monitored by 17 sensors:

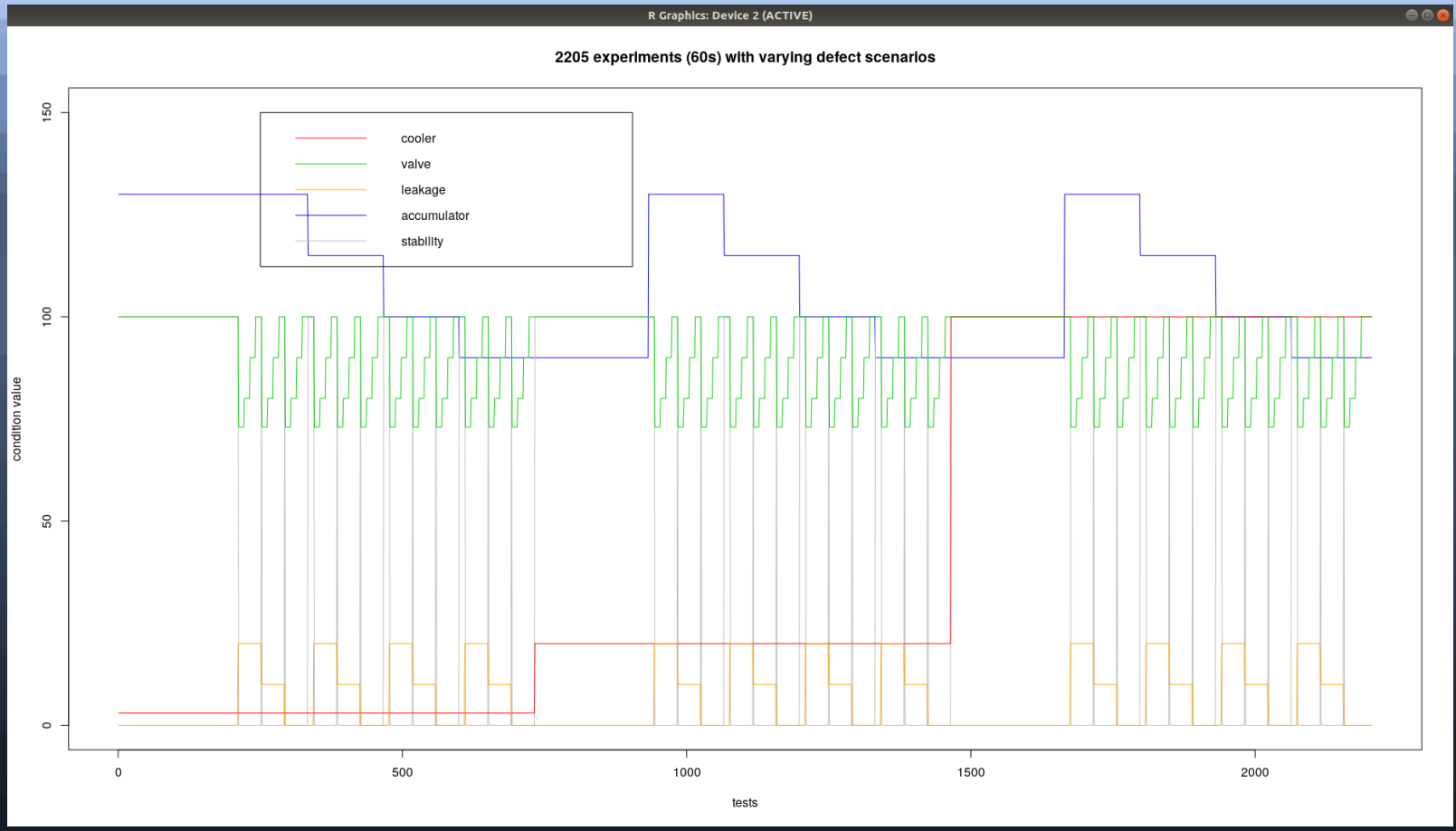
PS1-PS6	pressure	[bar]	100Hz
FS1 -FS2	flow	[l/min]	10Hz
TS1-TS4	temperature	[°C]	1Hz
VS1	vibration	[mm/s]	1Hz
EPS1	pump power	[W]	100Hz
CP	cooling power	[kW]	1Hz
CE	cooling efficiency	[%]	1Hz
SE	system efficiency	[%]	1Hz

Condition Monitoring

Hydraulic system defect conditions

	condition classes			
Cooler	100	20	3	
Valve	100	90	80	73
Pump Leakage	0	1	2	
Accumulator	130	115	100	90
Stability	0	1		
	optimal	→		*worst case*

Condition Monitoring



Hydraulic system experiments (60 sec. load profile) conducted for varying defect scenarios

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Condition Monitoring

Defect recognition by statistical properties of sensor data

results
of independet analysis by Otmar Mak:

Defects can be identified with small classification errors already by data of only 6 Sensors (out of 17)

Cooler	(CE,CP, PS1,PS2)
Main valve	(PS2)
Pump	(FS1, SE)
Accumulator	(PS1, SE)

Condition Monitoring

Summary of Results

	Helwig/ Schütze	Mak				
	correlation	correlation	accuracy condition	accuracy defect	sensors	algorithm
Cooler	100,0%	99,5%	99,7%	99,8%	CE,CP,PS1,PS2	SSC
Valve	100,0%	99,7%	99,8%	99,8%	PS2	SSC
Pump	98,0%	99,2%	98,8%	98,9%	FS1,SE	SSC
Accumulator	88,8%	91,8%	81,6%	92,5%	PS1, SE	SSC
Average	96,7%	97,6%	95,0%	97,7%	6	

Comment:
SSC series state classifier (*proprietary*)
correlations according to Spearman

Higher classification succes rates achieved with fewer sensors

Condition Monitoring

Comparing Results

significant sensor data: Schütze et al[2017], S. 17

Cooler:	*CE, CP, PS5*
Valve:	EPS1, FS1, PS1, PS2, PS3, SE
Pump:	EPS1, FS1, PS1, *VB1*
Accumulator:	EPS1, FS1, PS1, PS2, PS3, SE

Correlations, as published in comparison table :
Scenario 1: industrial application (predefined constant work cycles)
Schütze et al[2017], S. 23

Disclaimer: estimates of correlation may not be *perfectly* comparable, e.g. because of potentially differing cross-validation procedures

Higher classification succes rates achieved with fewer sensors

Condition Monitoring

Advantages of deployed algorithm

* automatic filtering of sensor data according to relevance for diagnosing conditions
* capability of ***massive data reduction***, if the diagnosing problem allows it
* low resource requirements in terms of computing power and storage
* ***uniformly high defect recognition rates*** (in presented demo) with varying diagnostic problems
* easy way to ***minimize sensor requirements*** or to determine accuracy gain by additional sensor data

Condition Monitoring

Remark on Experimental Design and Cross-Validation

* *10-fold cross-validation* was conducted by randomly partitioning complete sample into 10 approx. equal-sized subsets, resulting in training sample size 1985, and test sample size 220, while training samples always contained 9 out of 10 defect-free experiments (the experimental design contained only 10 defect-free experiments out of 2205)

Condition Monitoring

References

Schütze et al[2017]: A. Schütze (Lehrstuhl f. Messtechnik Uni Saarland, FR Systems Engineering), N.Helwig, T. Schneider (Zentrum für Mechatronik und Automatisierungstechnik GmbH): *Condition Monitoring mit statistischen Methoden: Was uns Rauschen und Kurtosis über Maschinenzustände sagen können*. (2017)

Helwig et al[2015]:
Helwig N., Pignanelli E., Schütze A.: *Condition Monitoring of a Complex Hydraulic System using Multivariate Statistics*, 2015 (oben zitiert)

predictive maintenance

Utilization of historical Condition Monitoring Data

* If Condition Monitoring data are continuously logged together with defect conditions, **predictions** can be derived **from historical data**, whether or when in near future defect conditions or breakdowns are likely to occur - and preventative mainentance can be scheduled

Demo: predictive analytics