Sensor data analysis

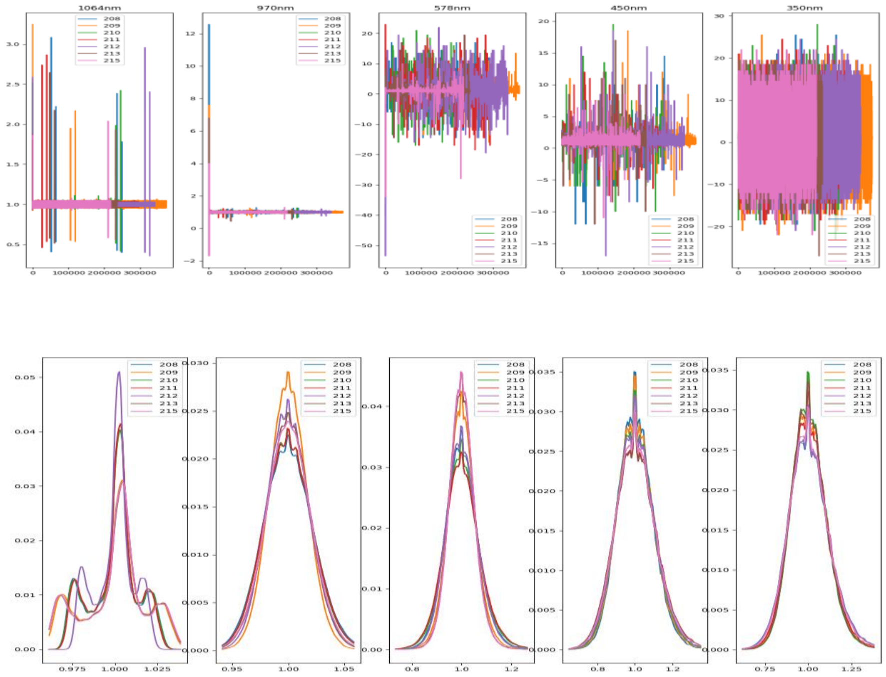
-Radicle –seminar 18th Oct 2018

Sensor data characteristics

- Non-stationary and stochastic even within short time-frames
  - long periods of apparent trends up or down
  - sudden and unpredictable changes in direction
- Manifestation of a Markow process, i.e. random process whose future probabilities are determined by its most recent values
  - →Short-Time Fourier Transform (STFT) and even wavelet spectrum analysis were fruitless
  - →various methods looking for structural signal patterns failed

We have concentrated on methods dealing with statistical signal properties

Normalized signals and their PDF's



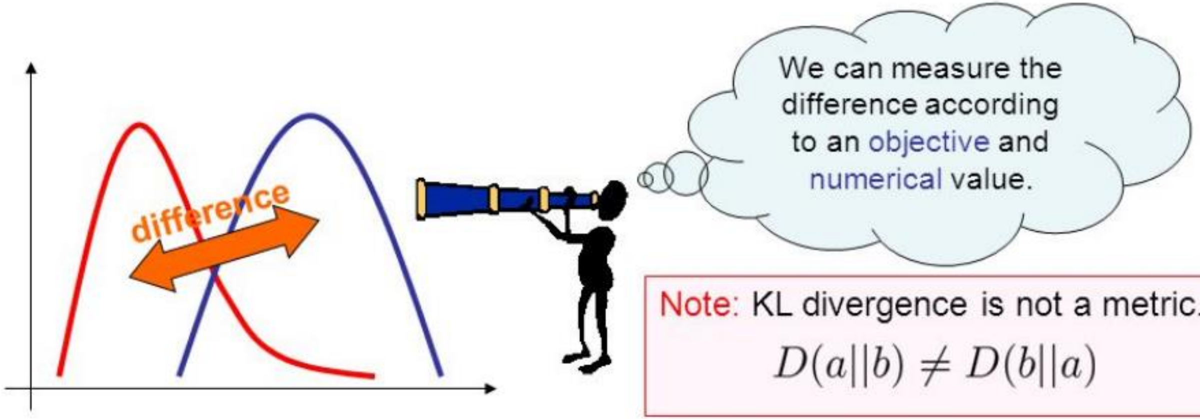
- 1064nm photo diode signal forms a non-Gaussian distribution whereas the rest of the signals form a somewhat Gaussian distribution
- Statistical signal processing method based on PDF divergency from reference signals has been applied

Tests at TWI with Inconel718 2.1mm

Kullback-Leibler (KL) divergence

- A measure of the difference between two probability distributions: $a(x)$ and $b(x)$

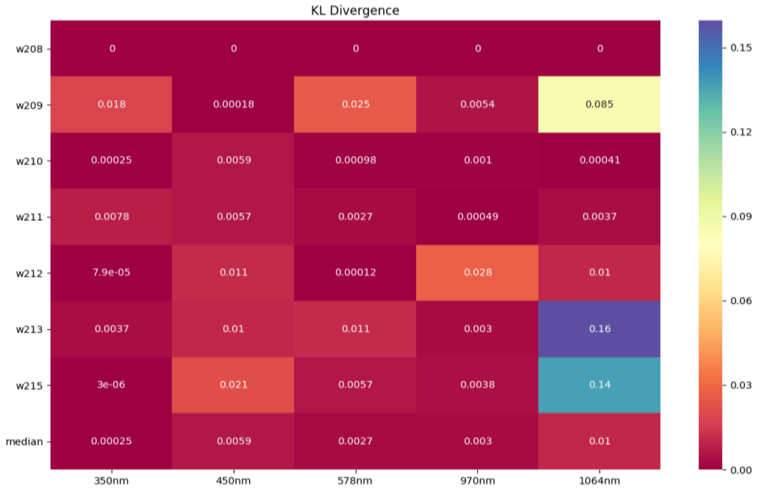
$$D(a||b) \equiv \int dx a(x) \log \left(\frac{a(x)}{b(x)} \right)$$

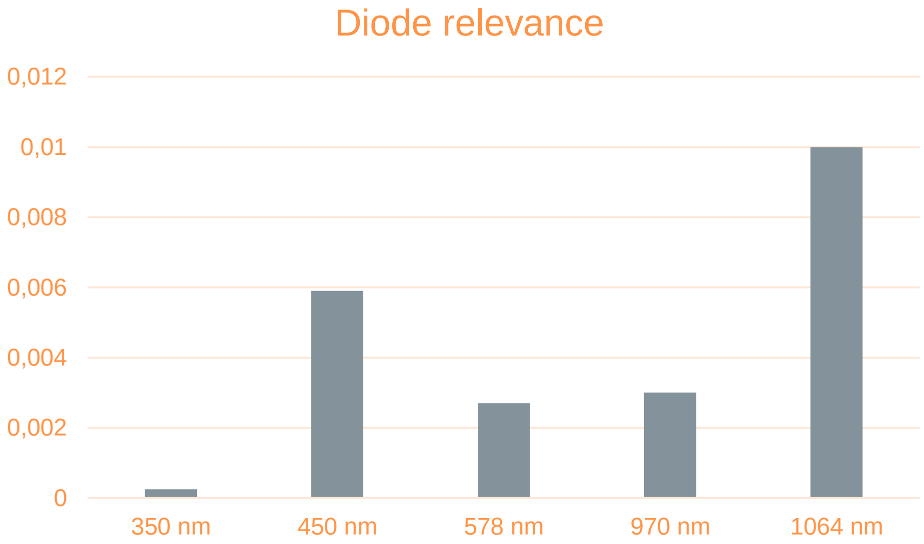


Note: KL divergence is not a metric.

$$D(a||b) \neq D(b||a)$$

Diode separation capabilities





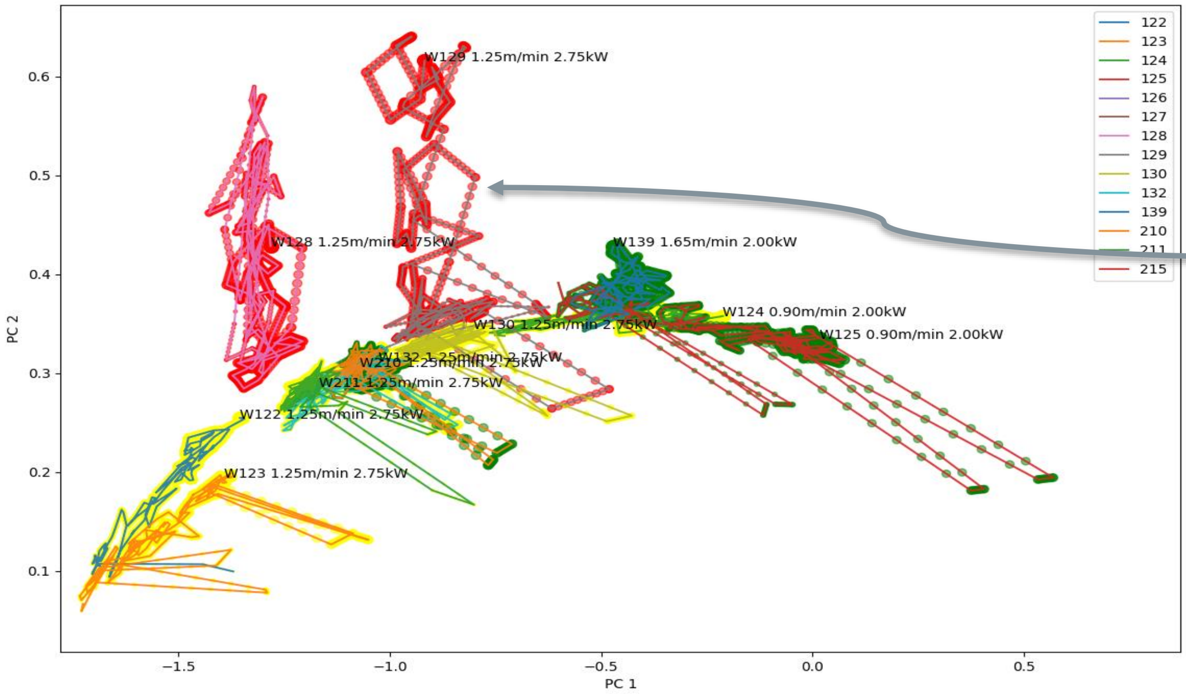
Tests at TWI with Inconel718 2.1mm

Method for process observation - simplifide

a) Perform sample normalisation using relative change (t1/t0)
b) Select n reference welds
c) Calculate the KL-divergence of all welds using the photodiode data (n-dimensional KL-divergence vector per weld where n is nbr_of_sensors * nbr_reference_welds)
d) Perform PCA (Principal Component Analysis) for the KLD-vectors to reveal the latent feature space in the hope that the latent features would reveal what kind of drift there might be in the signals

Various hyperparameters has effect on the result, but the amount of the parameters has been minimised

The method can identify fit up issues



Weld ID	Welding Speed (mm/min)	Focal position (mm)	Laser Power (W)
W122	1250	-2	2750
W123	1250	-2	2750
W124	900	-2	2000
W125	900	-2	2000
W126	1250	-2	2750
W127	900	-2	3500
W128	1250	-2	2750
W129	1250	-2	2750
W130	1250	-2	2750
W132	1250	-2	2750
W139	1650	-2	2000
W209	900	-2	2000
W210	1250	-2	2750
W211	1250	-2	2750
W215	1650	-2	2000

TABLE 2. REFERENCE WELD WELDING PARAMETERS

Weld ID	Welding Speed (mm/min)	Focal position (mm)	Laser Power (W)
W136	1650	-2	3500
W208	1250	-2	2750
W209	900	-2	2000
W210	1250	-2	2750
W212	900	-2	3500
W213	1650	-2	2000

Tests at TWI with Inconel718 2.1mm

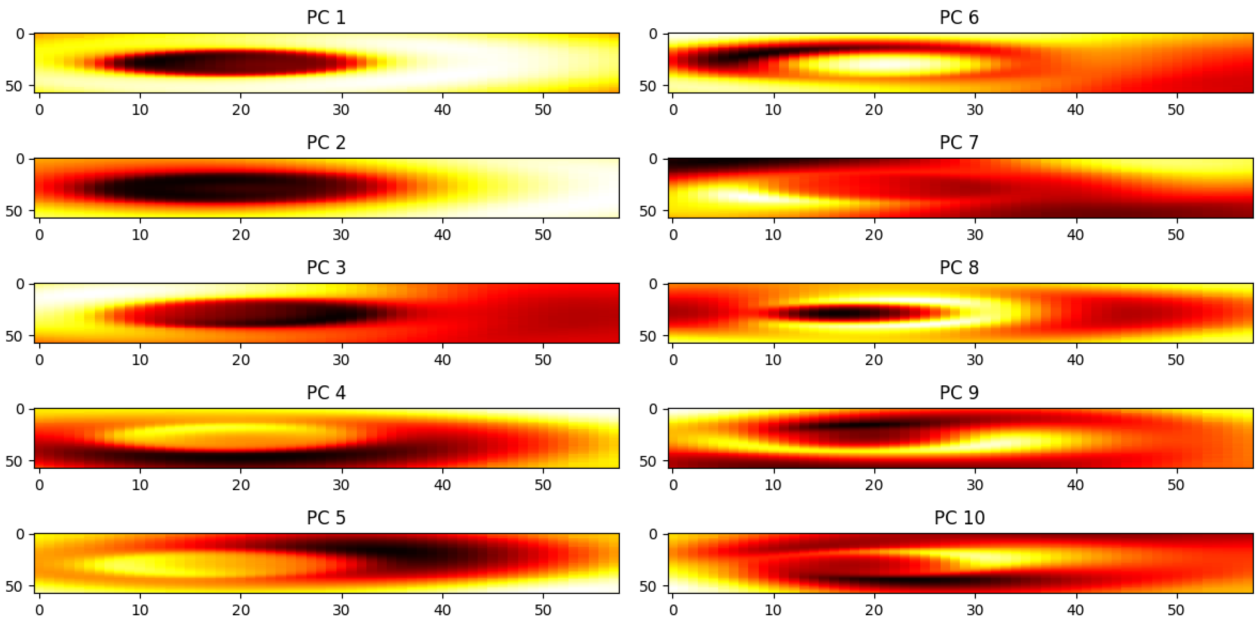
Process stability described as heatmaps

- The sensor signals should be stable when the process is stable
  - Overall stability can be explainable by observing the standard deviations of the signals
  - There should neither be significant drifts or quick jumps in the signals

  - The process stability heatmaps has been calculated as
    a) Calculating the sum of standard deviations of the PCs
    b) Scaling the sums between 0 and 1 where 1 is the lowest std

  - Heatmaps can be calculated based on photodiode or video data

Video data processing



10 principal components trained with all videos explaining 95 % of the variation

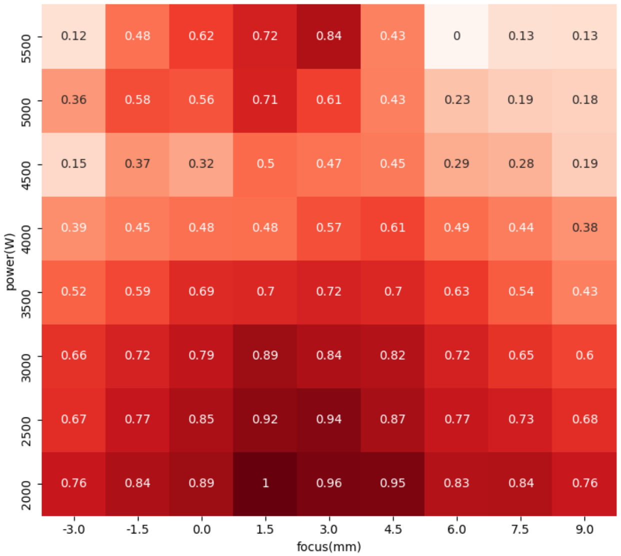
Summing up the variation of the PCs produces heatmap

Hotter the colour, the more significant the pixel

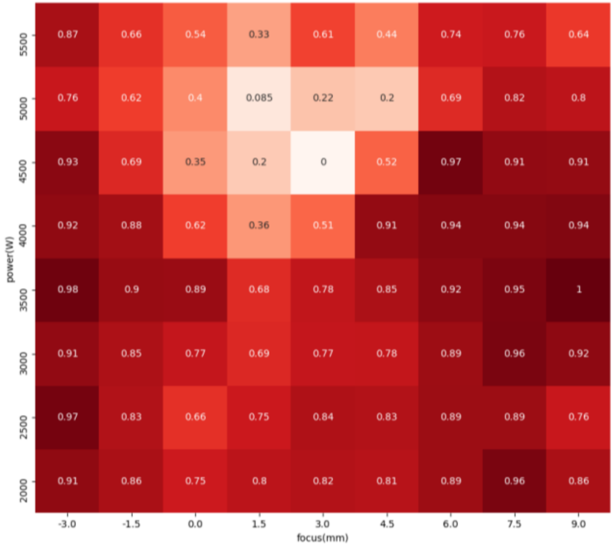
Tests at MTC with Inconel718 3.2 mm

Heatmaps with different power/focus combinations

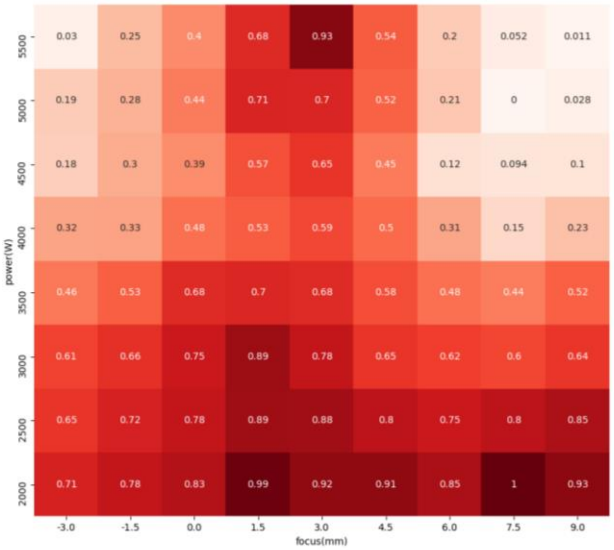
Raw photodiode data



KLD photod. data

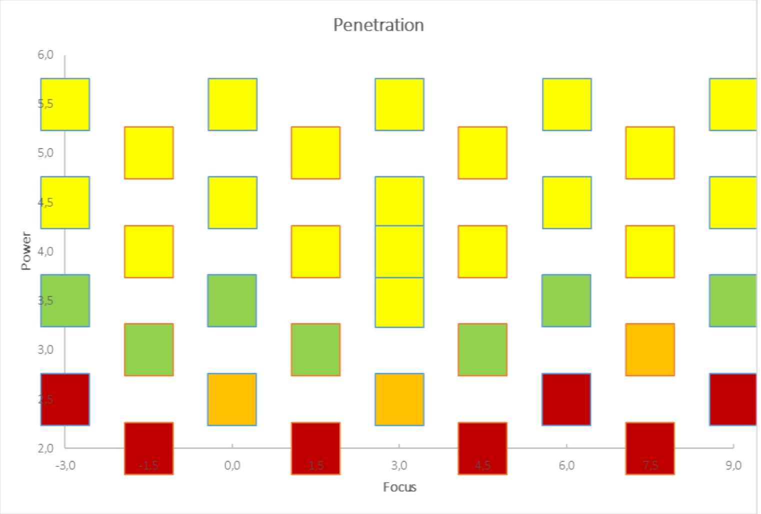


Video data



Tests at MTC with Inconel718 3.2 mm

Penetration quality classes vs. video heatmap

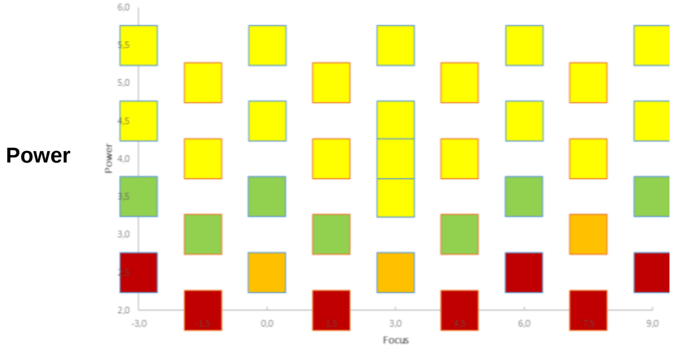


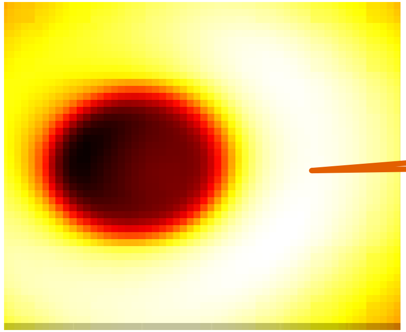
	Focus								
Power	**-3**	**-1,5**	**0**	**1,5**	**3**	**4,5**	**6**	**7,5**	**9**
5,5	0,03	0,25	0,4	0,68	0,93	0,54	0,2	0,052	0,011
5	0,19	0,28	0,44	0,71	0,7	0,52	0,21	0	0,028
4,5	0,18	0,3	0,39	0,57	0,65	0,45	0,12	0,094	0,1
4	0,32	0,33	0,48	0,53	0,59	0,5	0,31	0,15	0,23
3,5	0,46	0,53	0,68	0,7	0,68	0,58	0,48	0,44	0,52
3	0,61	0,66	0,75	0,89	0,78	0,65	0,62	0,6	0,64
2,5	0,65	0,72	0,78	0,89	0,88	0,8	0,75	0,8	0,85
2	0,71	0,78	0,83	0,99	0,92	0,91	0,85	1	0,93

Borderline partial → full penetration (3 - 3,5 kW) can be identified (accuracy can be improved by supervised learning techniques)

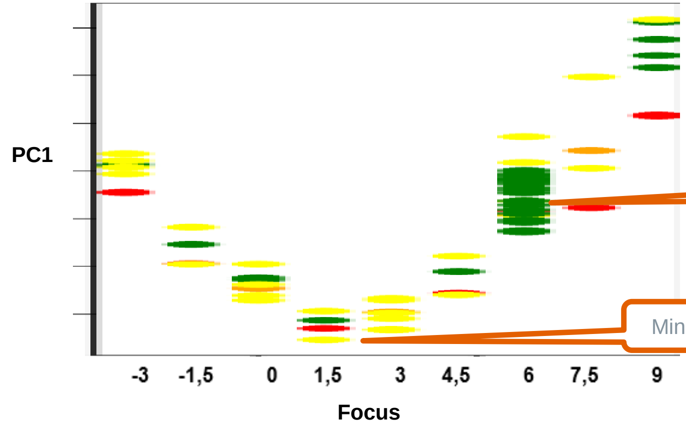
Tests at MTC with Inconel718 3.2 mm

Penetration quality classes vs. video PC1





Area contributing to PC1

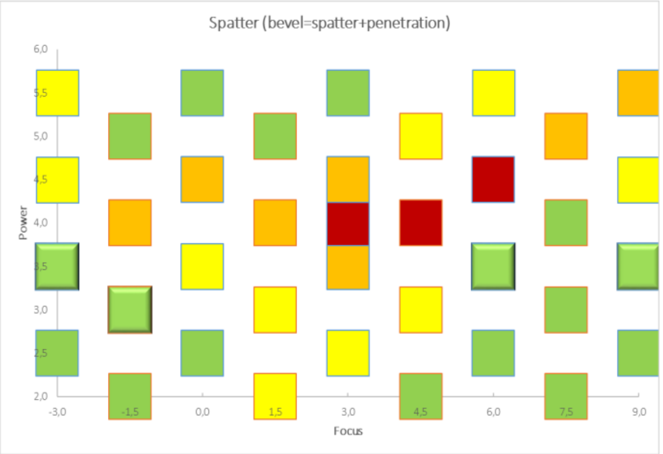


Quite large in sample variation?

Minimum at 1.5 – 3 mm?

Tests at MTC with Inconel718 3.2 mm

Spatter quality classes vs. diode KLD heatmap



	Focus								
Power	**-3**	**-1,5**	**0**	**1,5**	**3**	**4,5**	**6**	**7,5**	**9**
5,5	0,85	0,71	0,56	0,5	0,62	0,59	0,79	0,78	0,62
5	0,87	0,6	0,4	0,059	0,21	0,18	0,68	0,8	0,85
4,5	0,91	0,68	0,38	0,19	0	0,5	0,96	0,89	0,9
4	0,96	0,85	0,61	0,33	0,52	0,88	0,93	0,91	0,97
3,5	***0,96***	*0,88*	*0,87*	*0,66*	*0,77*	*0,84*	***0,97***	*0,95*	***0,98***
3	*0,96*	***0,82***	*0,8*	*0,67*	*0,75*	*0,75*	*0,88*	*0,93*	*1*
2,5	0,95	0,87	0,86	0,78	0,82	0,81	0,89	0,93	0,98
2	0,93	0,83	0,76	0,78	0,75	0,79	0,85	0,93	0,91

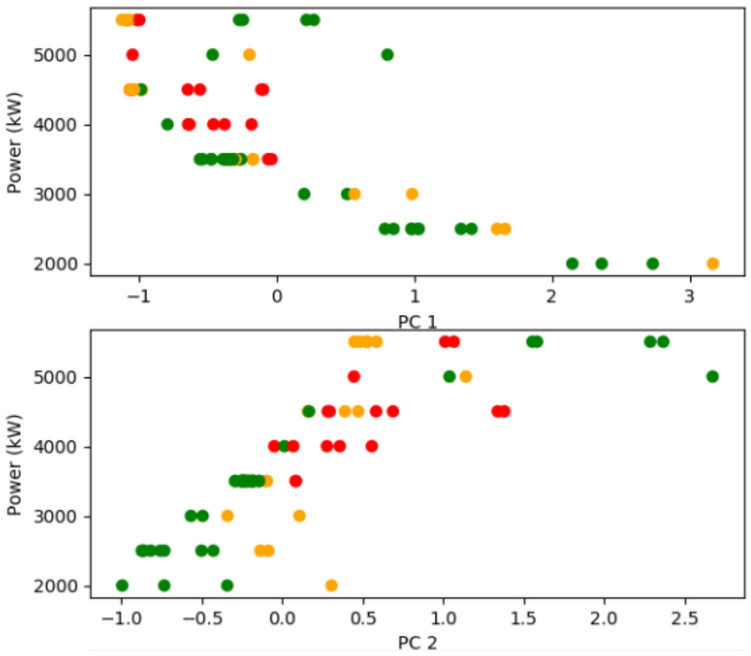
KLD > 0,95 and P 3-3.5 kW

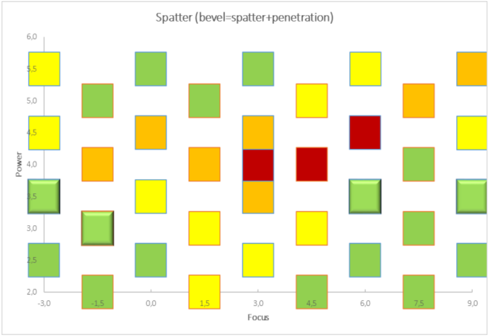
Combinig diode and video heatmaps it is possible to identify the process sweet spots

- Using part of the data for algorithm training it is possible to improve the accuracy

Tests at MTC with Inconel718 3.2 mm

Spatter quality classes vs. photodiode PC 1 and PC 2





Unfortunately no direct correlation with spatter

Tests at MTC with Inconel718 3.2 mm

Conclusion

- Raw signal data, KLD photodiode data and PCA transformed video data produces quality heatmaps in completely unsupervised way. The quality heatmap approach is based on the hypothesis that the standard deviation of the signals is an indicator for stable process hence good quality.
- It is possible to reason the process window(s) based on these heatmaps, however the accuracy is somewhat modest
- Common to the methods is that they all find a 1.5 - 3mm focus being special in sense of reaching the signal minimum in some sensor or principal component
- There is no direct correlation of the signal charasteristics with the quality ”traffic lights”