Data Storage in Gentelligent Components – A New Way for Self-Authentication

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What is Authentication?

- Verifying genuineness, origin vs. forgery
- Means
  - Historically: Stamps and seals on deeds
  - Handwriting: Signature
  - Forensics: *Fingerprint*

Impression of cylinder seal, Mesopotamia, Uruk Period (4100 BC–3000 BC)

Fingerprints, taken since 19th century

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  - Historically: Stamps and seals on deeds
  - Handwriting: Signature
  - Forensics: *Fingerprint*
- Analog Authentication
  - Differences exist
  - Significance to original is detectable

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Digital Authentication

- Digital data can be copied exact $\Rightarrow$ Fingerprints could be transfered to forgeries
- Digital signature was introduced (symmetric keys, e.g. AES 256)

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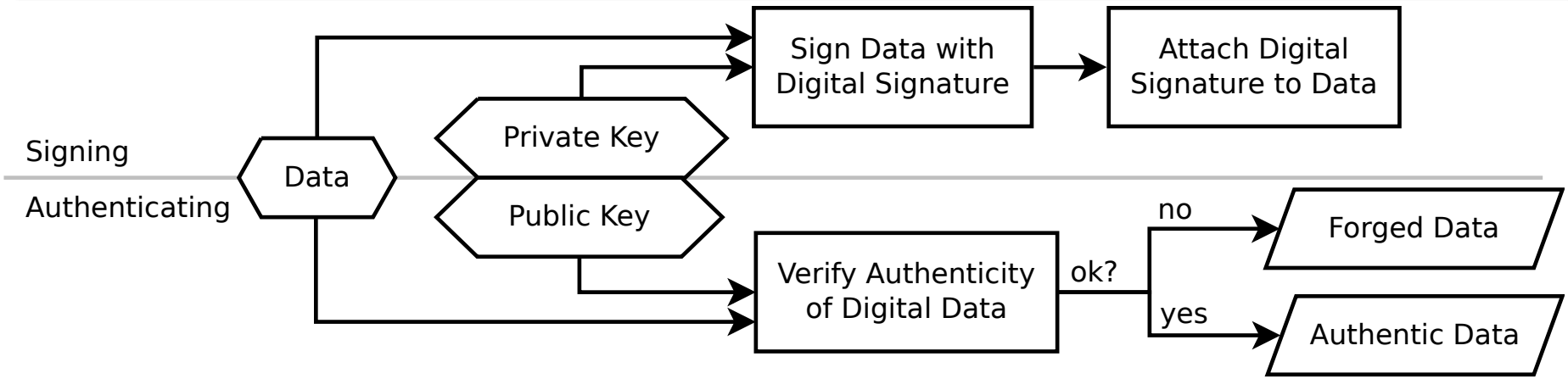

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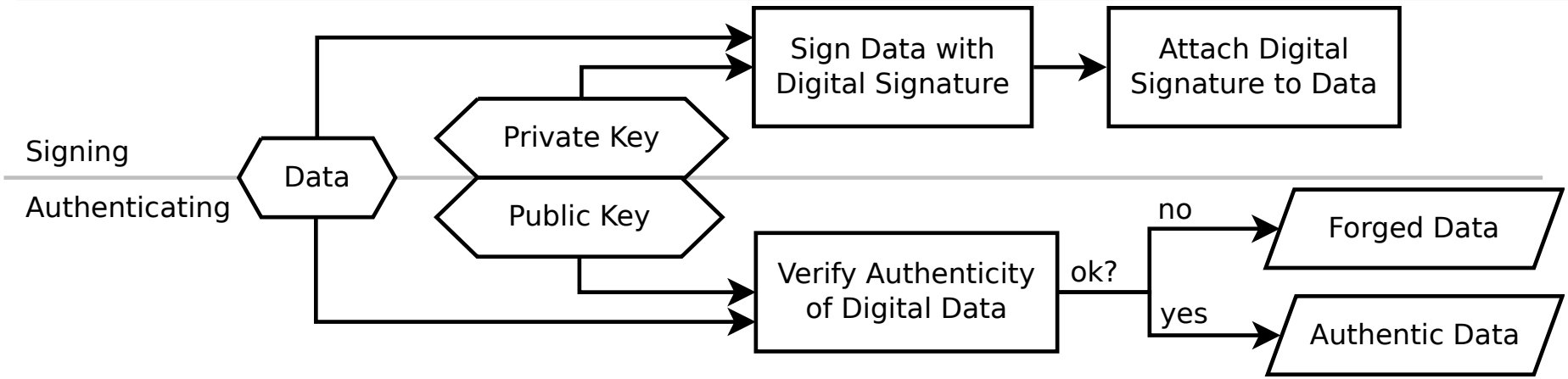
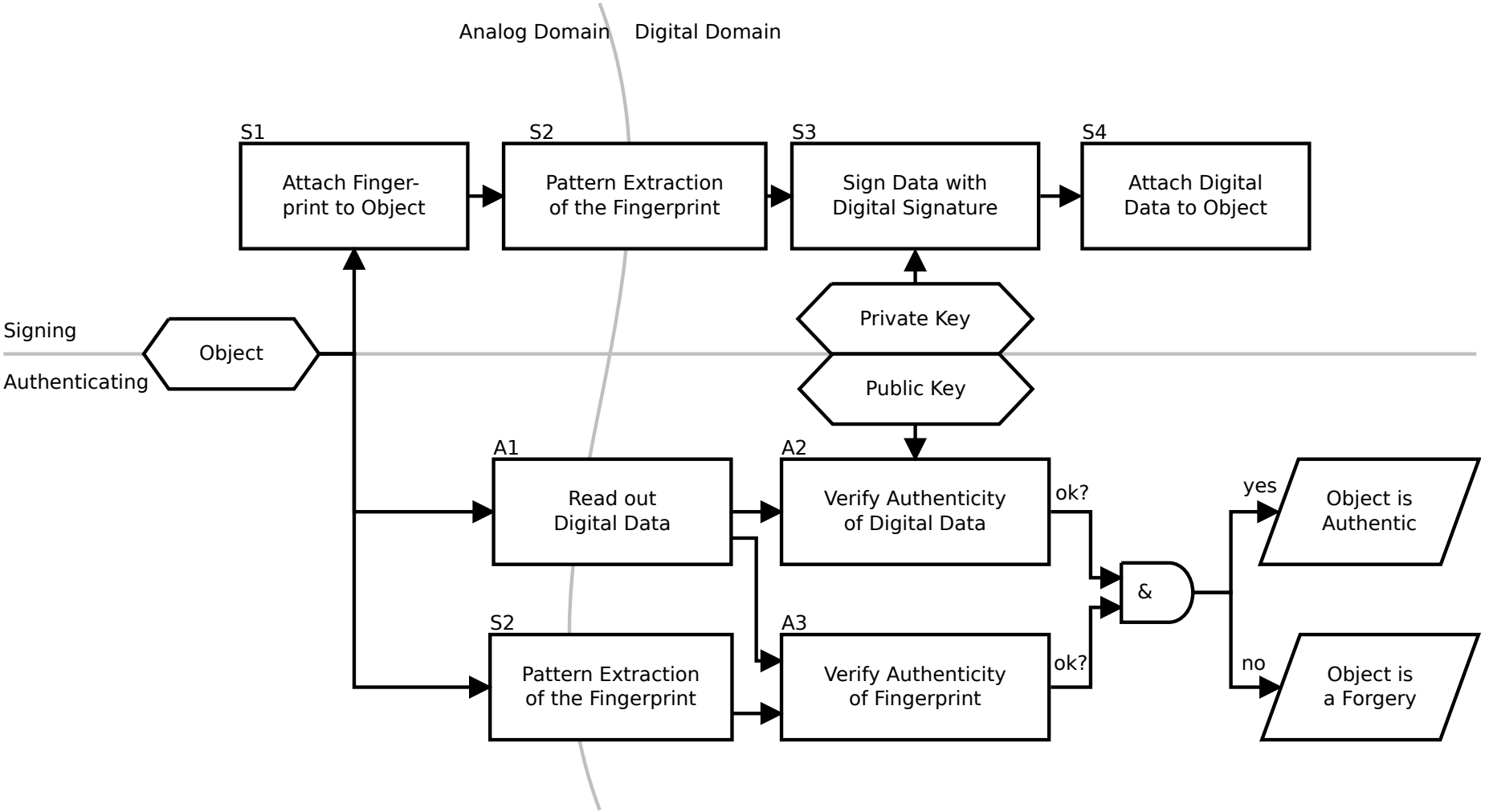


- Specific to data getting signed
- Specific to authenticating entity

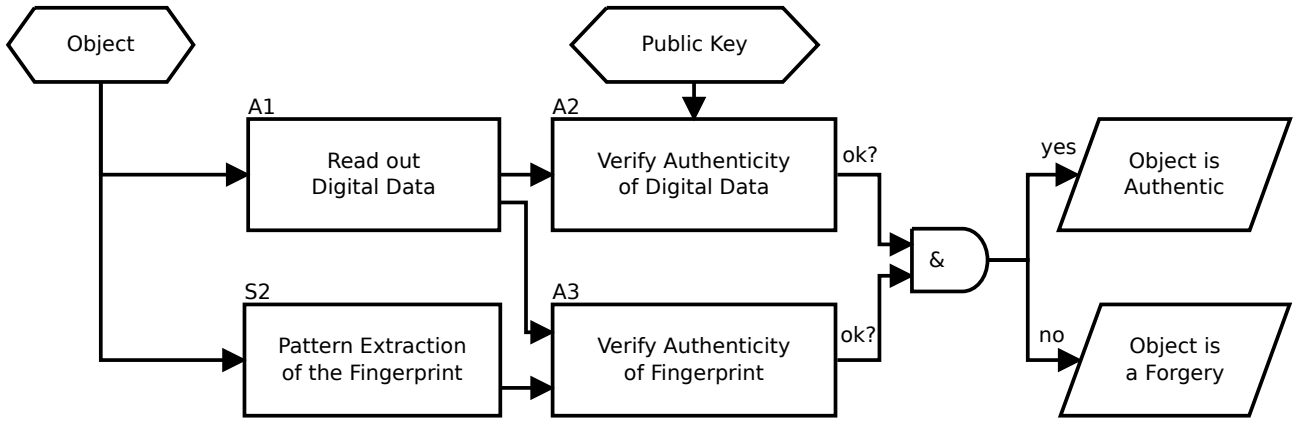
Digital Authentication for Objects

- Digital signature is cryptographically proved to be very strong
- Digital data is not related to real world
- Idea: Sign data describing specific component properties
  - None? Insert a random pattern!
  - Where to store data? Inherent!
- Every object/component may have a different pattern for verification

Self-Authentication



Why is this self-authentication?



Prior Information

- Public key of signer needed
- Public key can also be stored in digital data structure
  - Signed by root public key

  $\Rightarrow$ Only prior knowledge needed: Public root certificate

Signature For Documents

Object to be authenticated

Analog label: Image features of document itself

No hand-written signature needed

Digital label where digital information about the fingerprint is stored

Individual Bank Notes

Object to be authenticated

Analog label where a fingerprint is situated

Digital label where digital information about the fingerprint is stored

Individual Bank Notes

Object to be authenticated

Analog label where a fingerprint is situated

Digital label where digital information about the fingerprint is stored

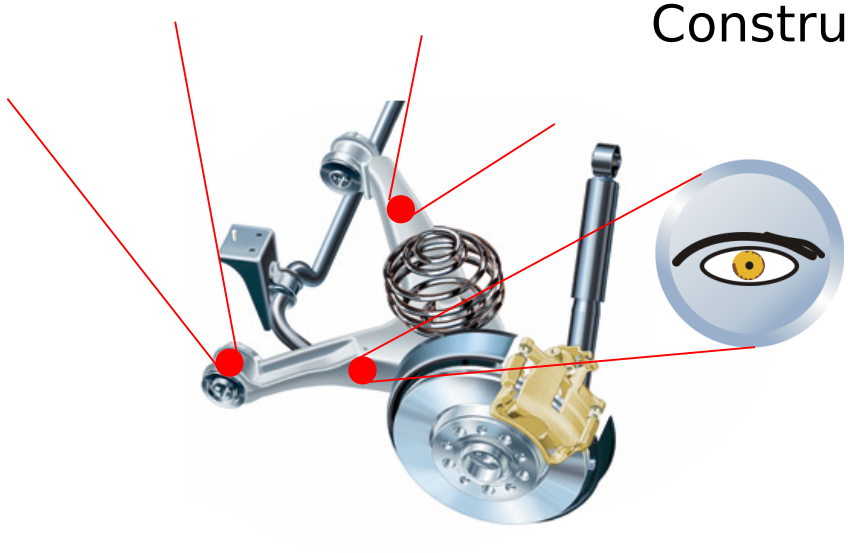
- Individual watermarks possible
- (Money is as virtual as information)

Why Inherent?

- Fingerprint
  - Must be fixed to component
  - Not inherent
    - Can get lost
    - Can be mixed up
- Data
  - Centralized from database
    - Accessability
    - Abuse to create forgeries
  - Not inherent
    - Can get lost
    - Can be mixed up

Gentelligent Components

Initial State of Component



Construction Plans

Current State of Component

Gentelligent Components

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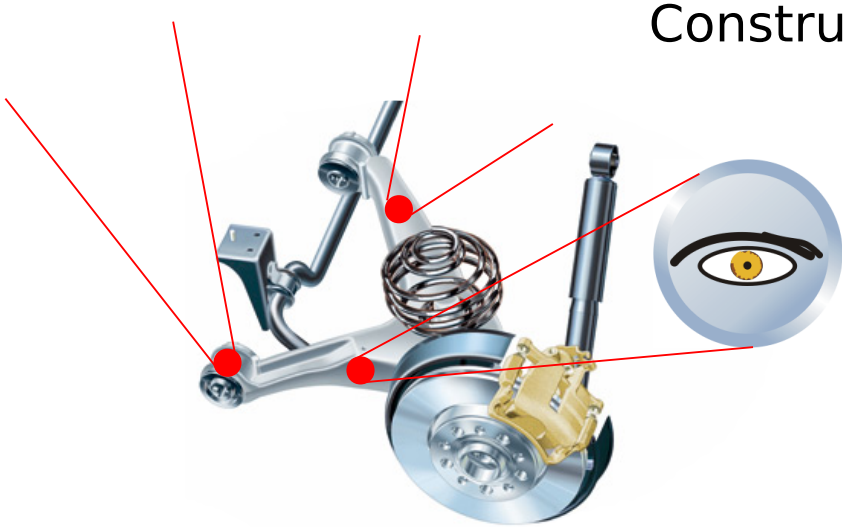
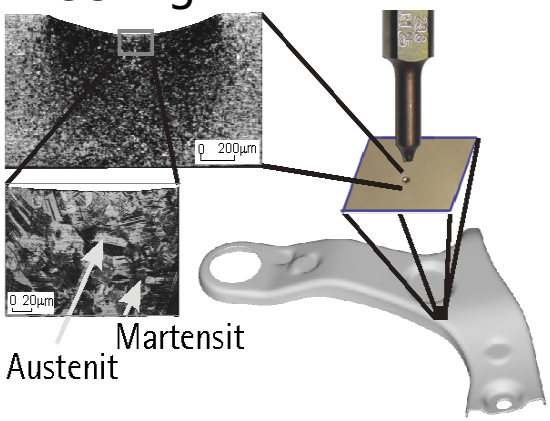


Construction Plans

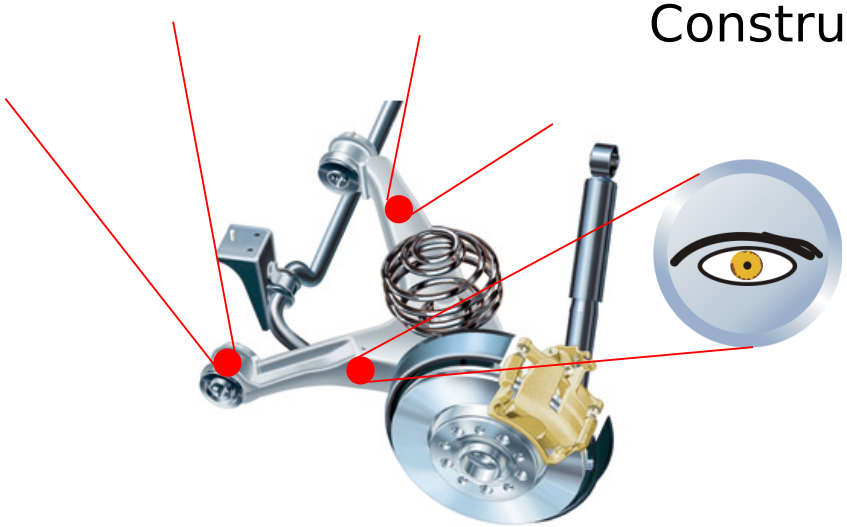
Current State of Component

"Feeling"



Gentelligent Components

Initial State of Component



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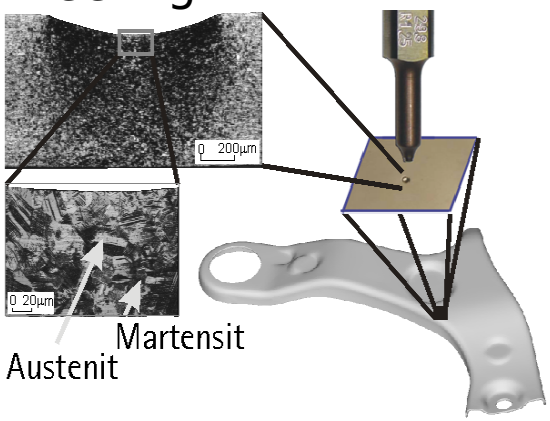
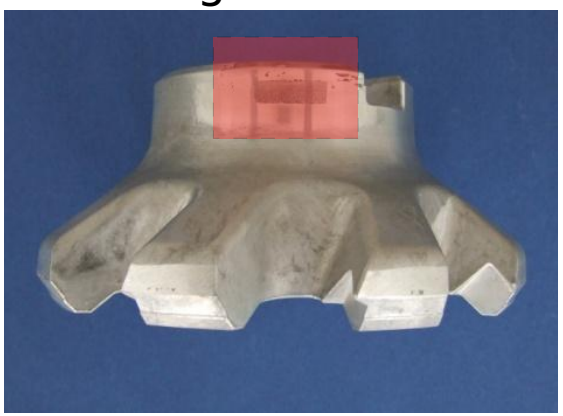


"Knowing"



Gentelligent Components

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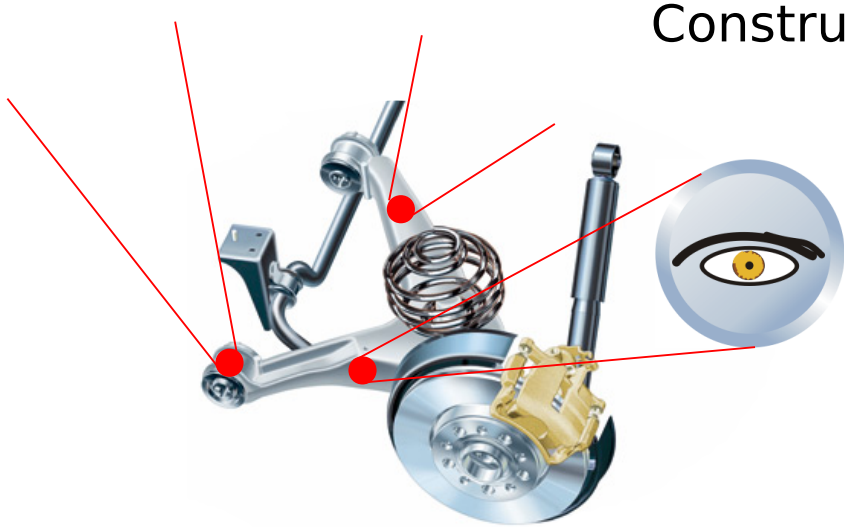

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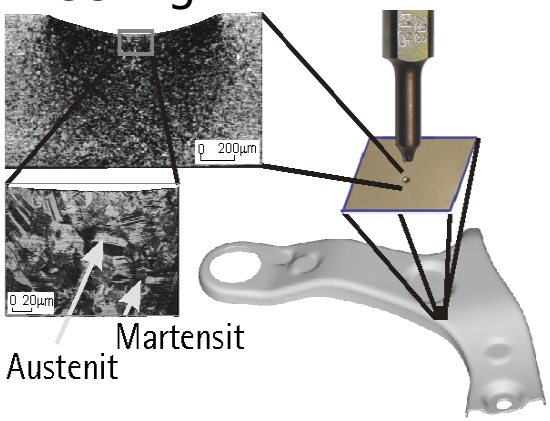

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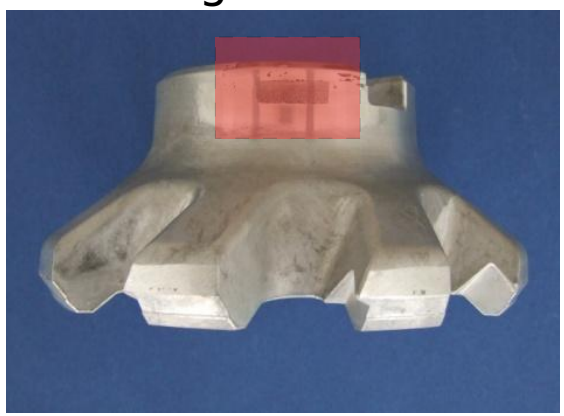
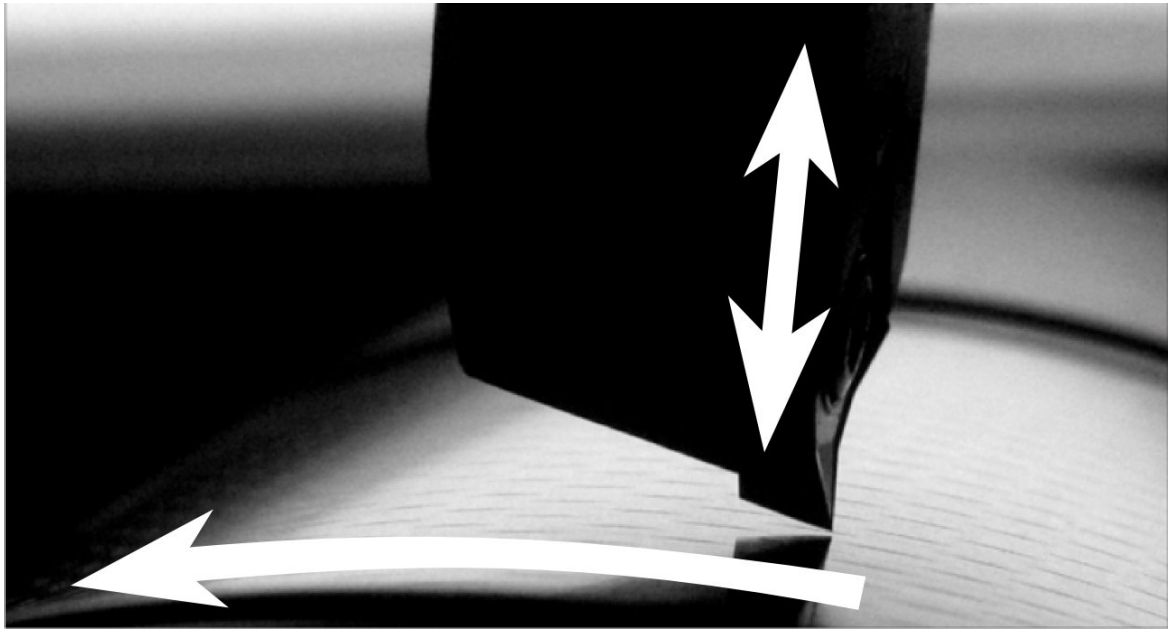
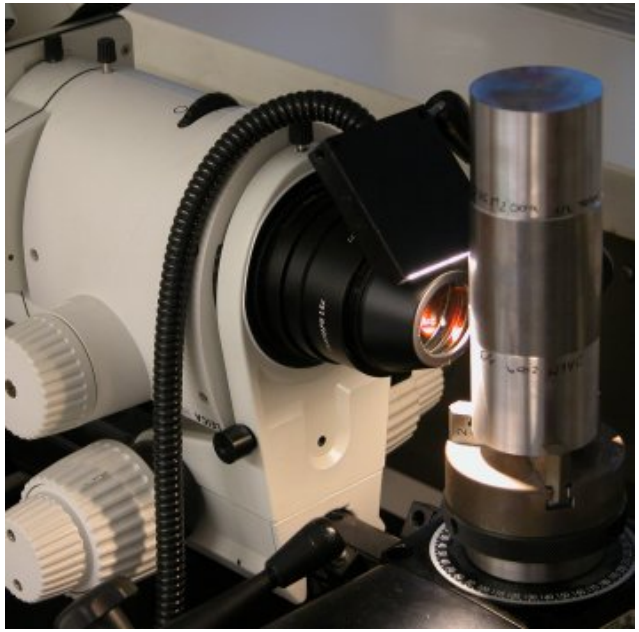


Using the knowledge

Genetics & Intelligence
⇒ Gentelligence

Inherent Data on Gentelligent Components





- Micro-structured surface for data storage
- Groove wound around component
- Cut in by Piezo tool during a turning process
- Depth is varied

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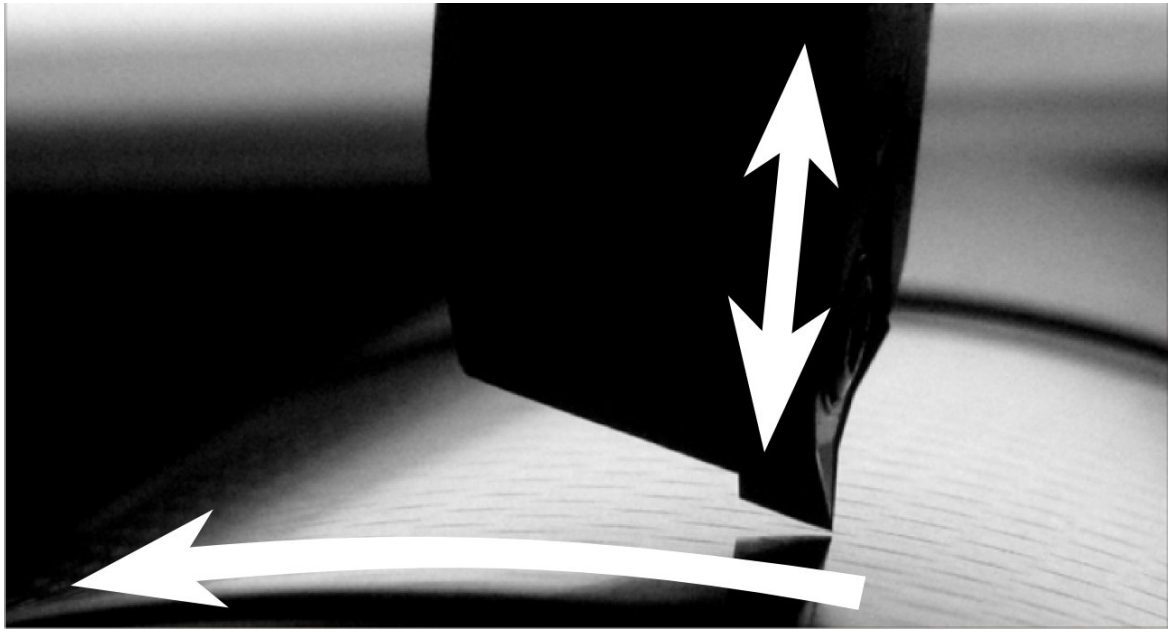
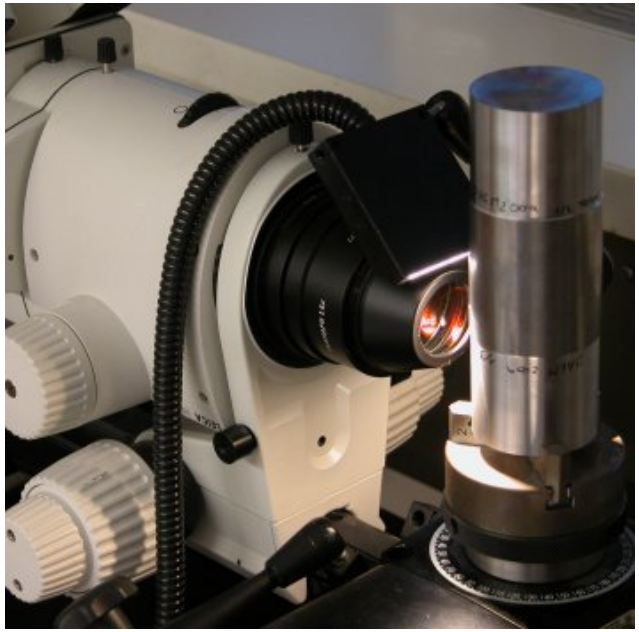
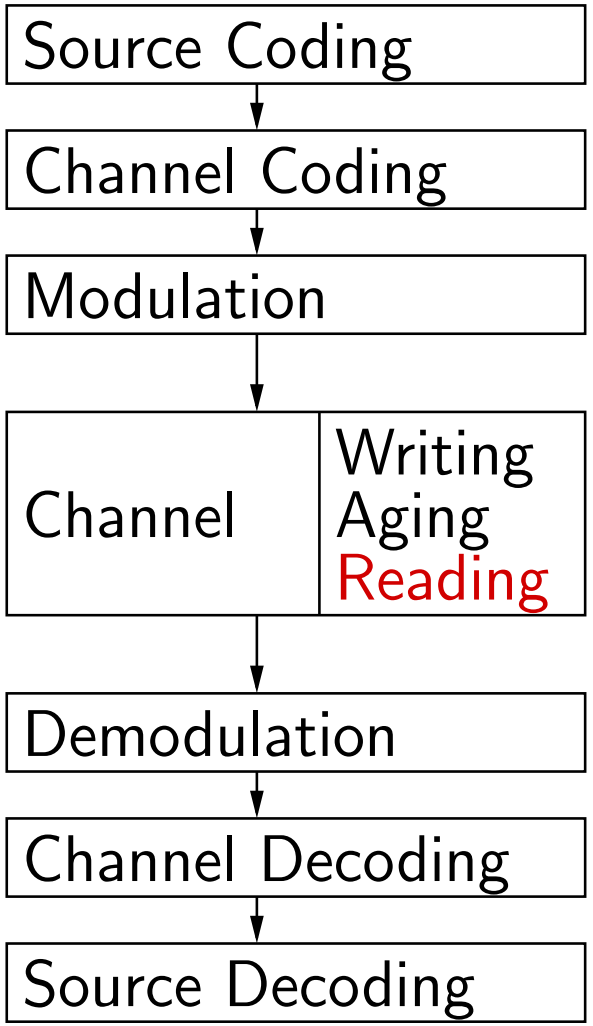




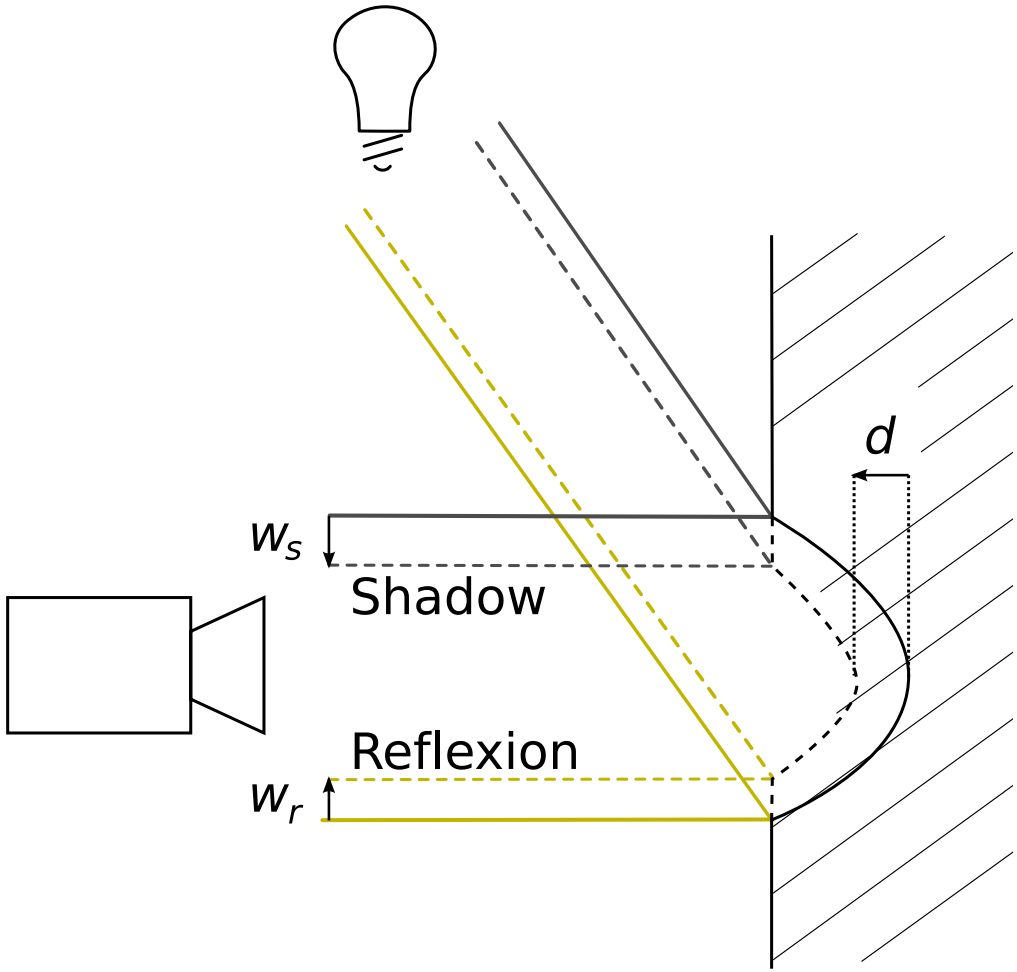
- Micro-structured surface for data storage
- Groove wound around component
- Cut in by Piezo tool during a turning process
- Depth is varied
- No digital structures can be created

Transmission principle

- Groove is imprint of the analog signal run of the Piezo tool
- Recovering the run means reconstructing the analog signal
- Data transmission system
- Depth reconstruction with optical means
- Re-use existing methods
- Only qualitative (no exact scaling) reconstruction needed

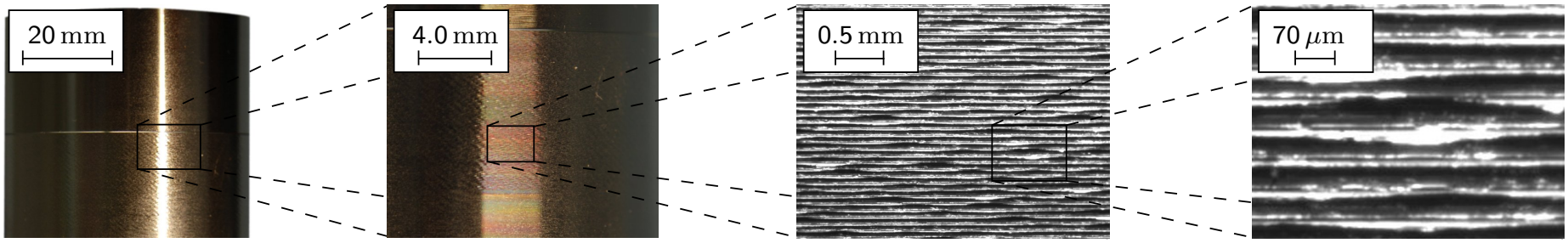


Depth from Directed Illumination



- Parallel illumination
- Groove consists of shadow and reflexion region
- Variation of groove depth by d shifts
  - shadow border by w_s
  - reflexion border by w_r
- We focus on reflexion
  - Geometry does not allow shadows and reflextions
  - Less image perturbation
- Edge tracking solves depth reconstruction qualitatively

Surface under Directed Illumination



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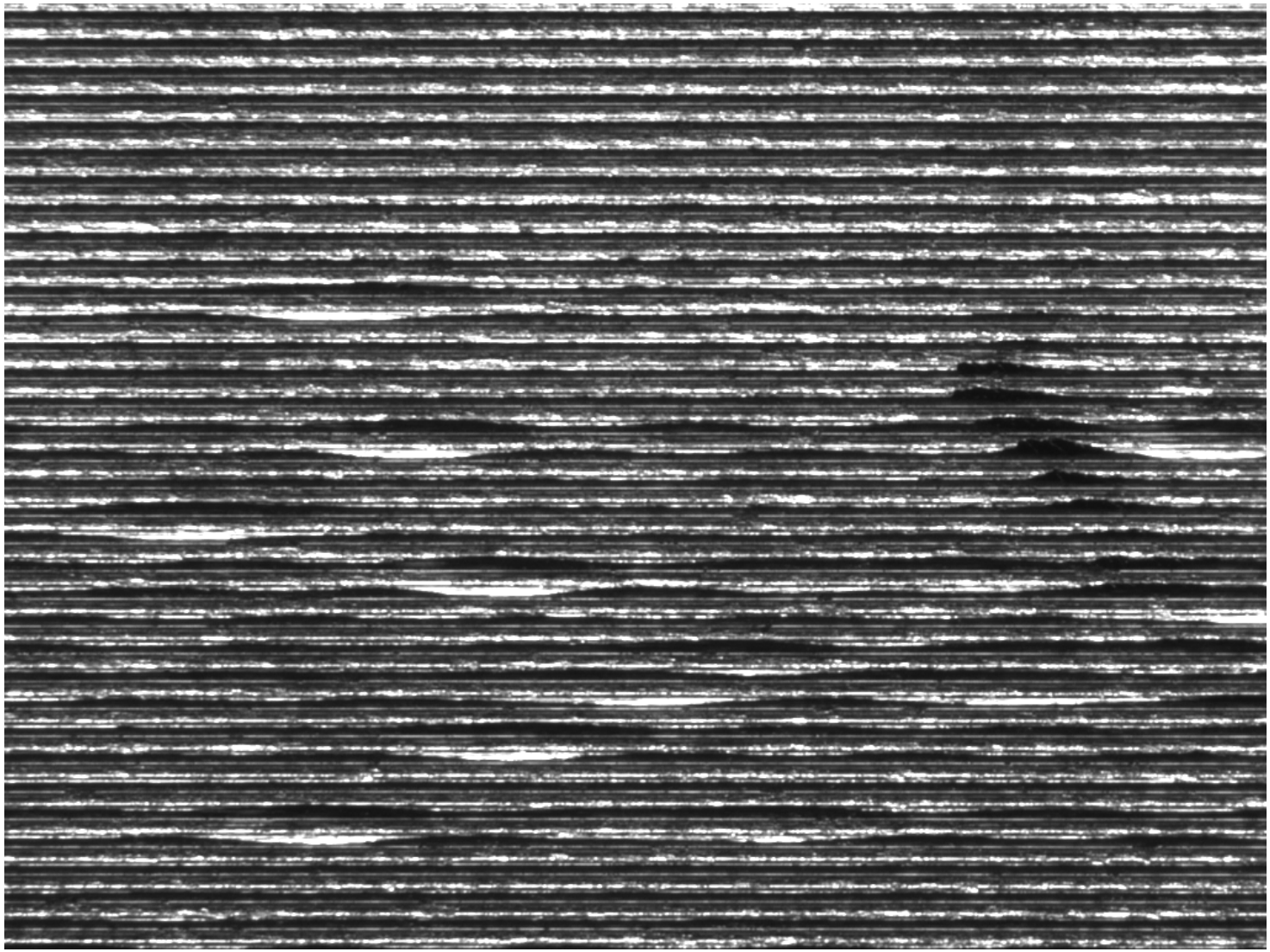

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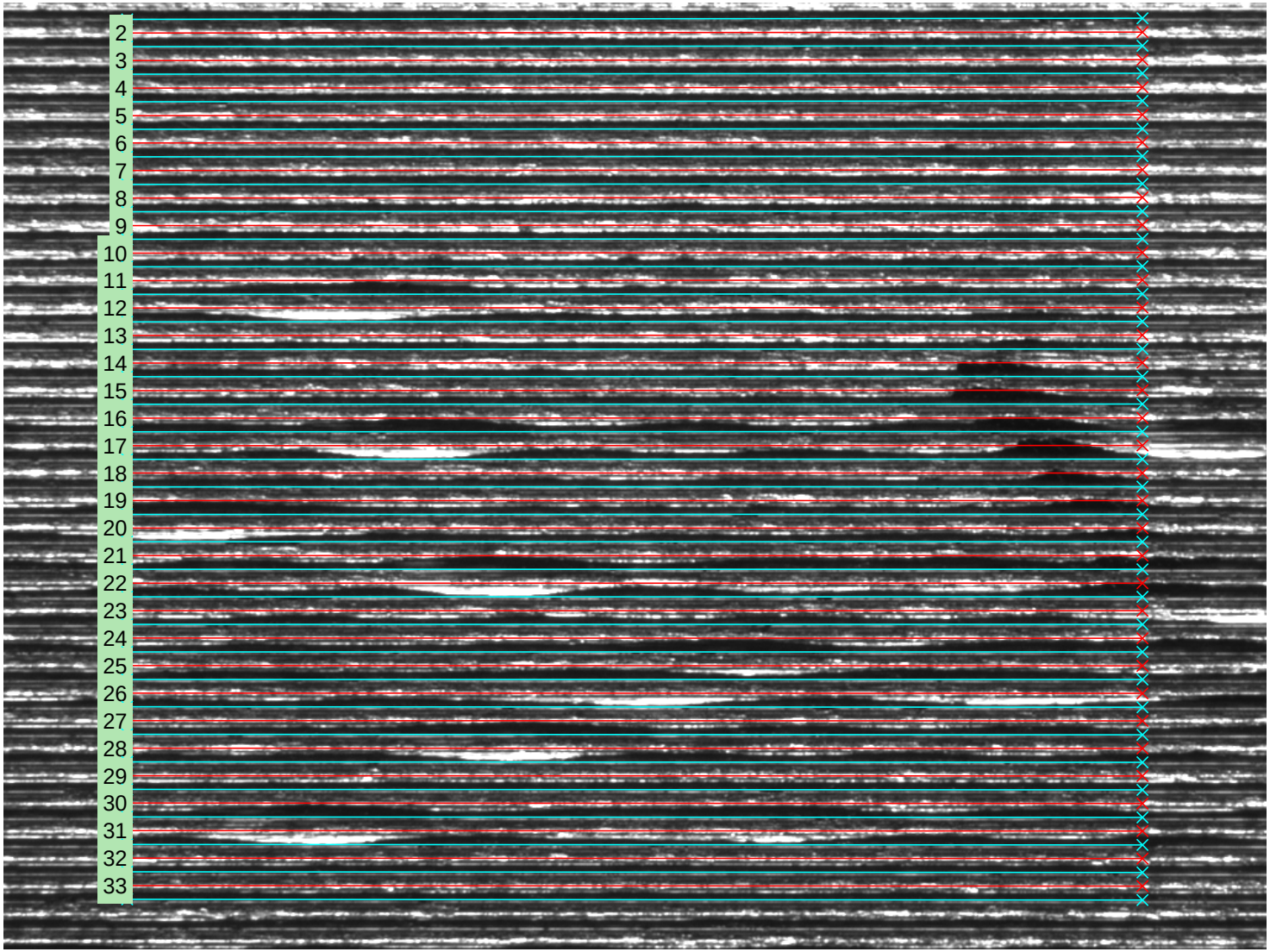

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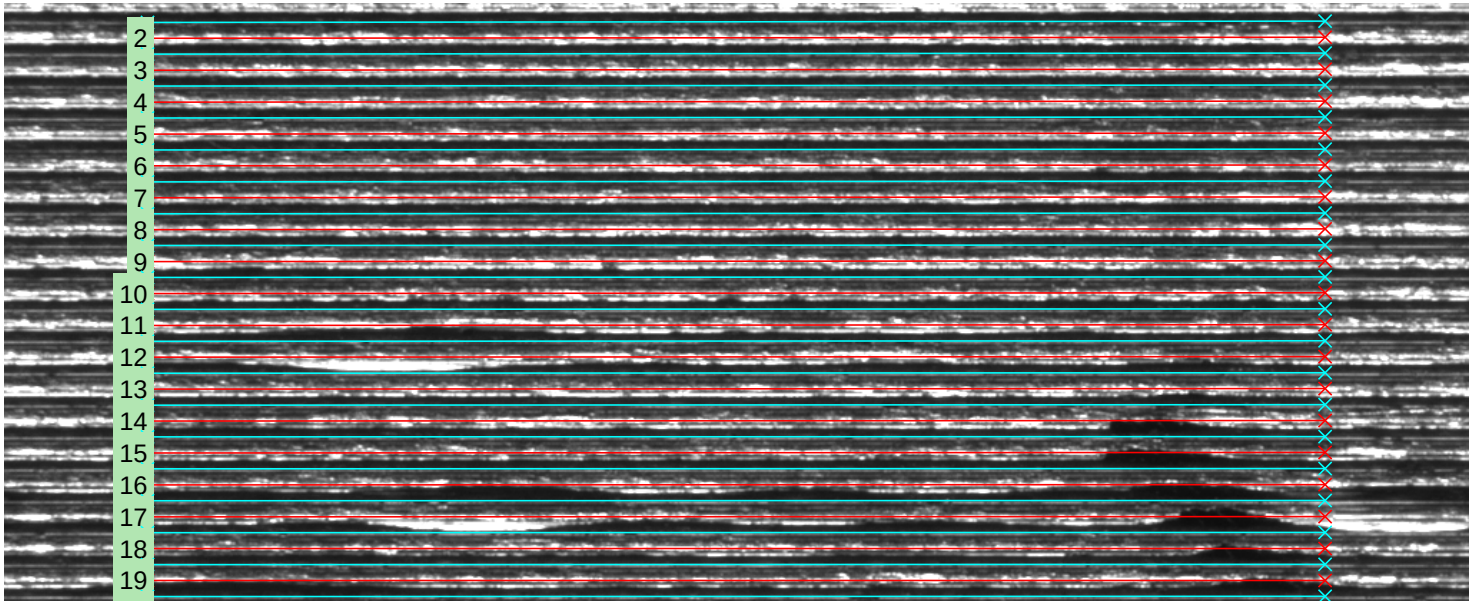
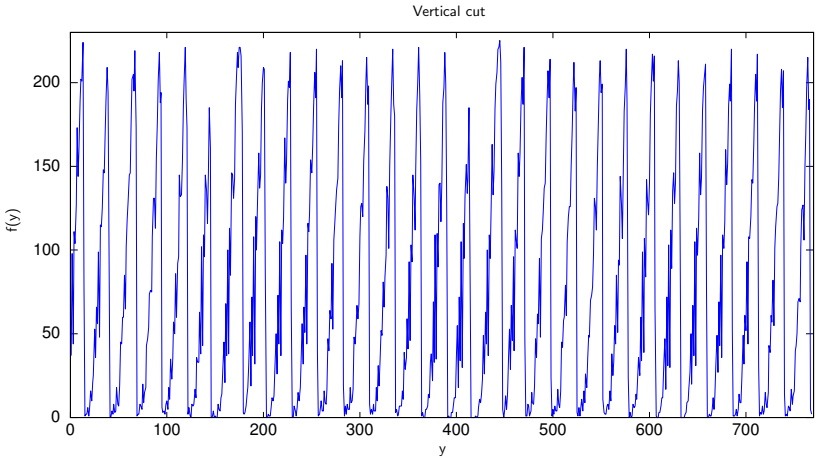


- Assumption: Groove runs approximately horizontal
- Perform several spectral analyses of the image $I(x, y)$ at column $x = x_i$ in vertical direction
- Filtering: Horizontal moving average (noise), vertical median (cutting artifacts)
- Vertical cut forms the 1D signal $f(y)$ which is analyzed

Inherent Data on Gentelligent Components

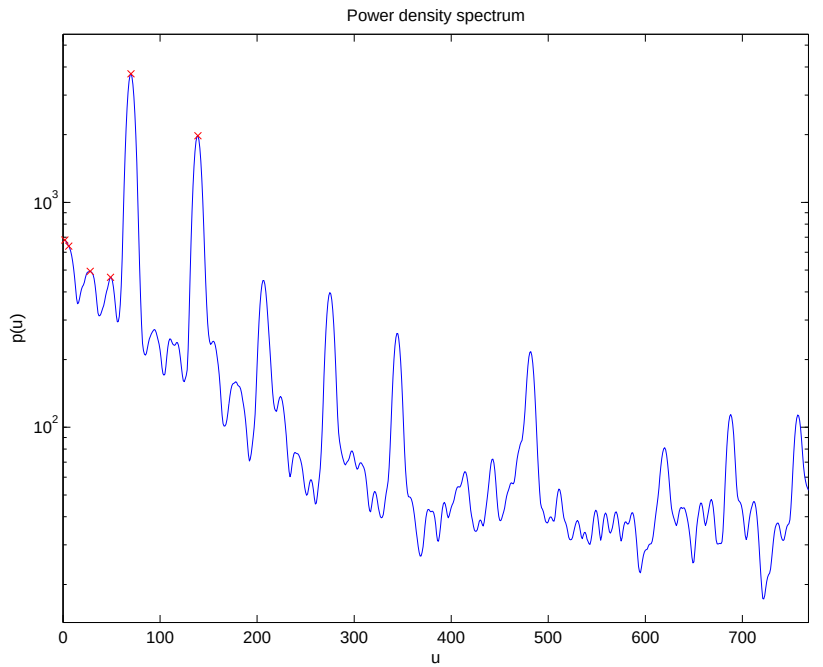
- Periodic reflexion area: $y = (n + \frac{1}{2})\lambda_0 + \phi_0$
- Distance λ_0 or frequency u_0
- Phase shift $\phi(u_0)$



Spectral Estimation

- $p(u) = {}^1/_R \sum_r |F_r(u)|$
- No phase information as $\phi(u)$ is not shift-invariant
- Phase estimation extention of average periodogram method[a]

[a] Dragon et. al., DAGM 2009



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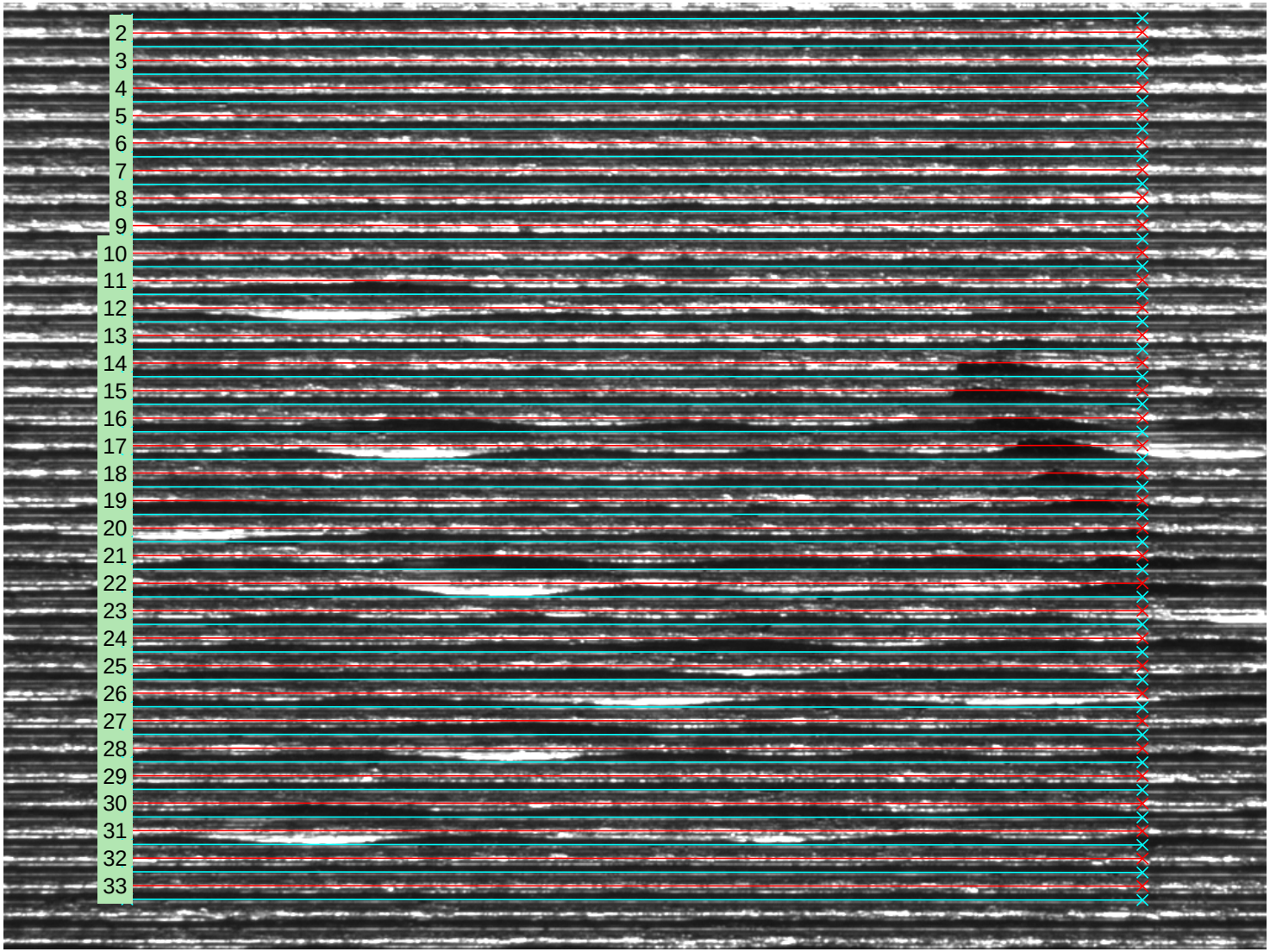
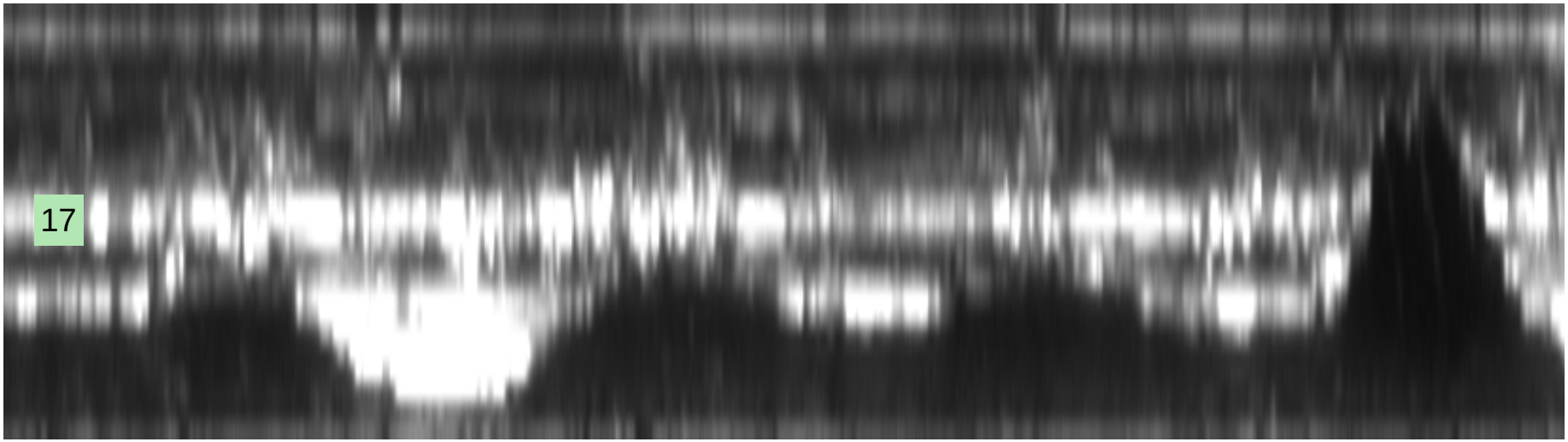
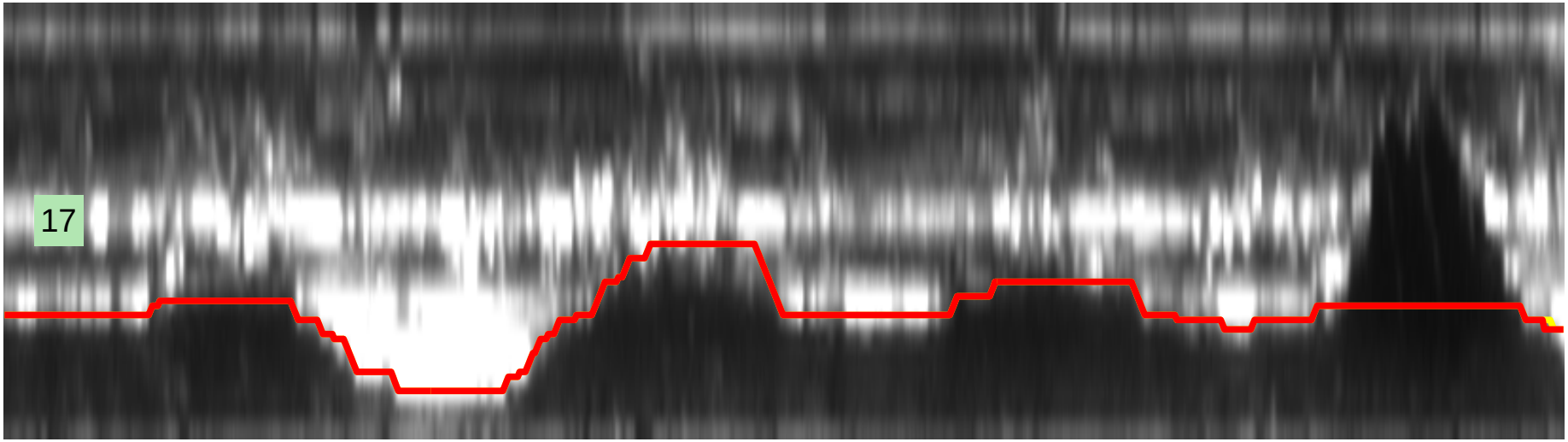




Extraction of the Groove Edge

- Model appearance of the groove edge
- Model movement of the Piezo tool
- Robust to perturbations



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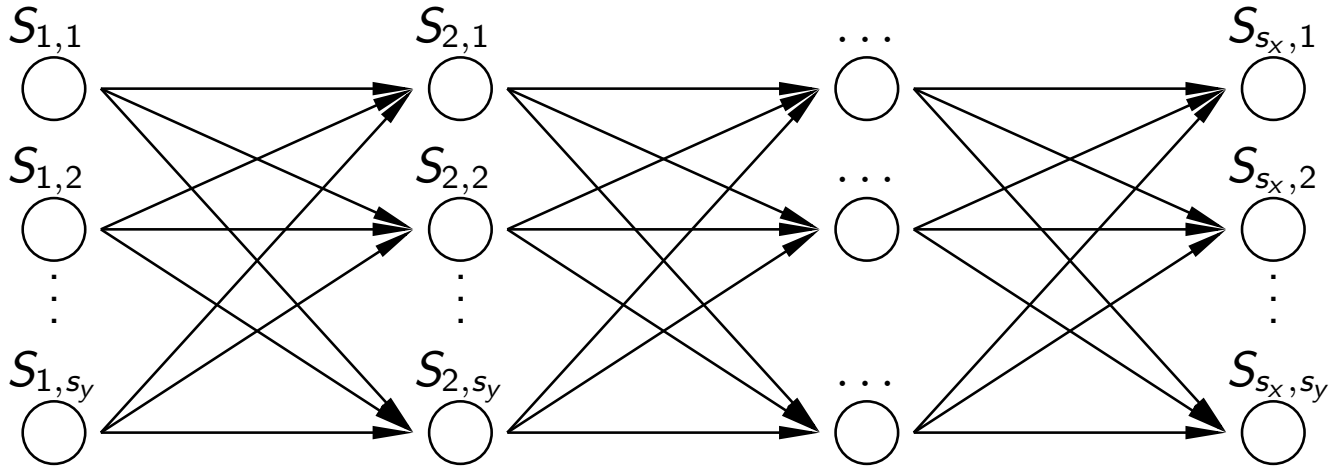
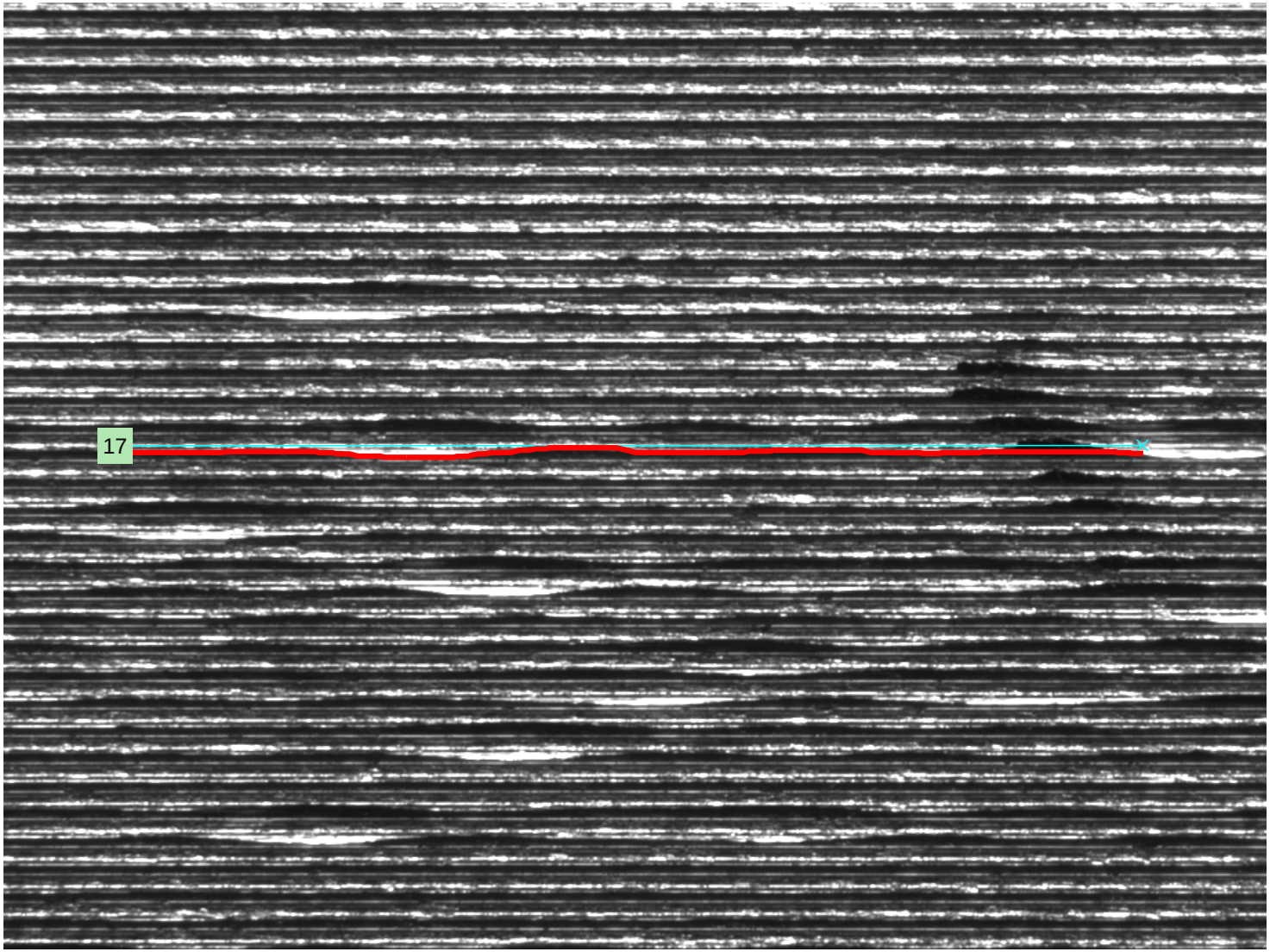


Adapted HMM Model

- Each node $S_{x,y}$ models one image pixel $I(x, y)$
- Observation probability: $p_o(x_i, y_i|I) \propto c - \frac{I(x_i,y_i+1)-I(x_i,y_i-1)}{2}$
- Transition probability: $p_t(x_{i+1}, y_{i+1}|y_i) \propto \mathcal{N}(\sigma^2, y_i)$
- Groove edge $Y = (y1, y2, \ldots, y_{s_x})$ is found with Viterbi algorithm finding maximum of $P = p_o(x_{s_x}, y_{s_x}) \prod_{i=1}^{s_x-1} p_t(x_{i+1}, y_{i+1}|y_i) p_o(x_i, y_i)$

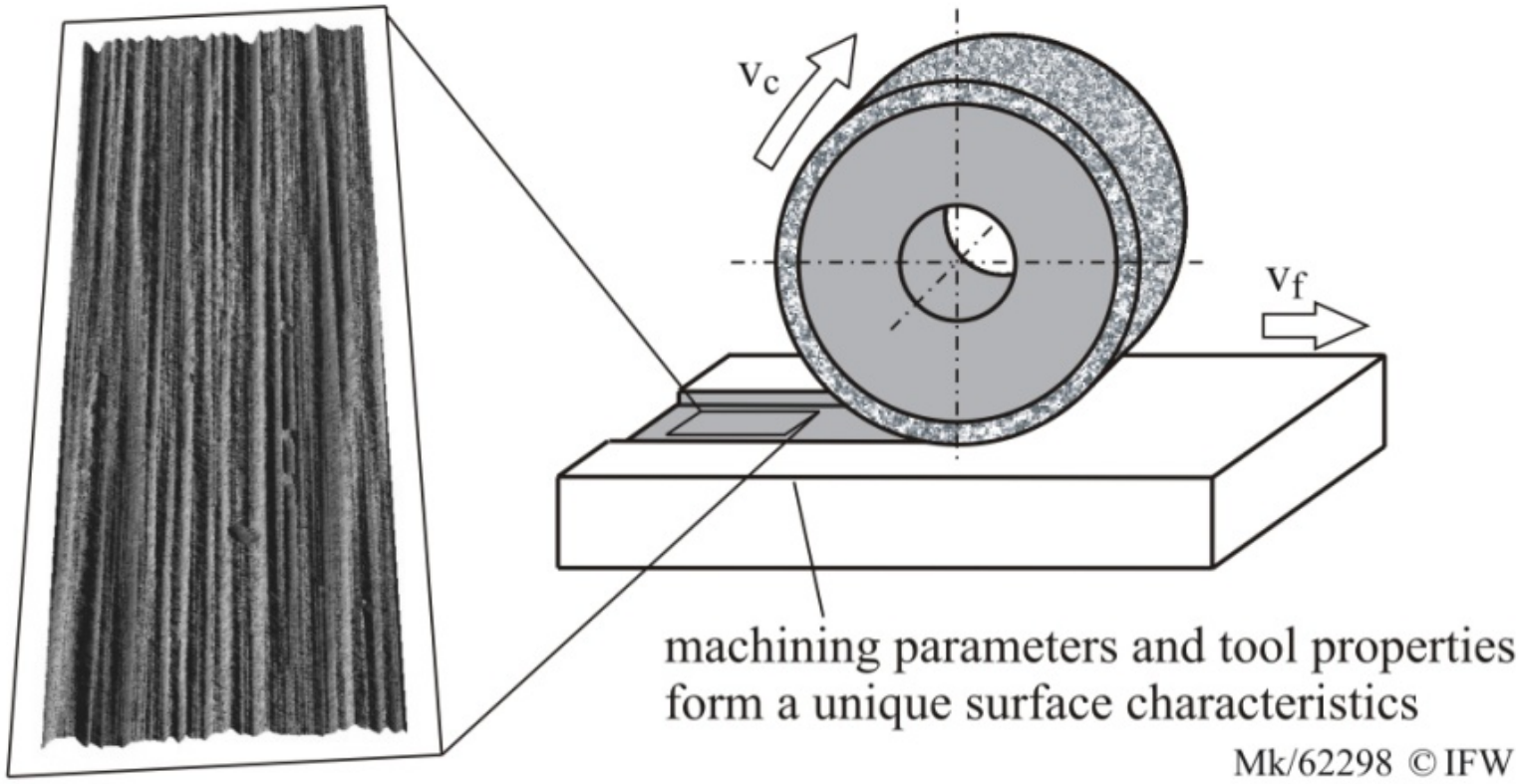
Inherent Data on Gentelligent Components



Fingerprint

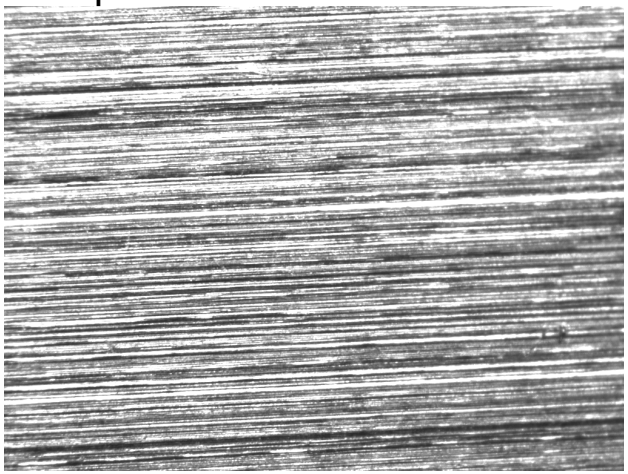
- Imprint of grinding process
- Pseudo-random

- Sample intensity profiles using directed illumination
- Compare using NCC

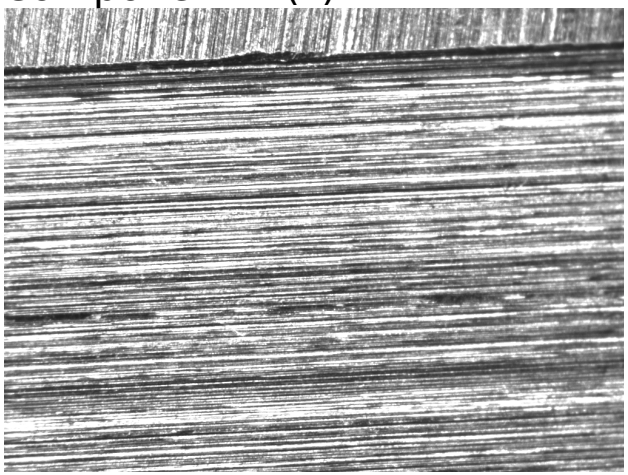


NCC of Depth Profile

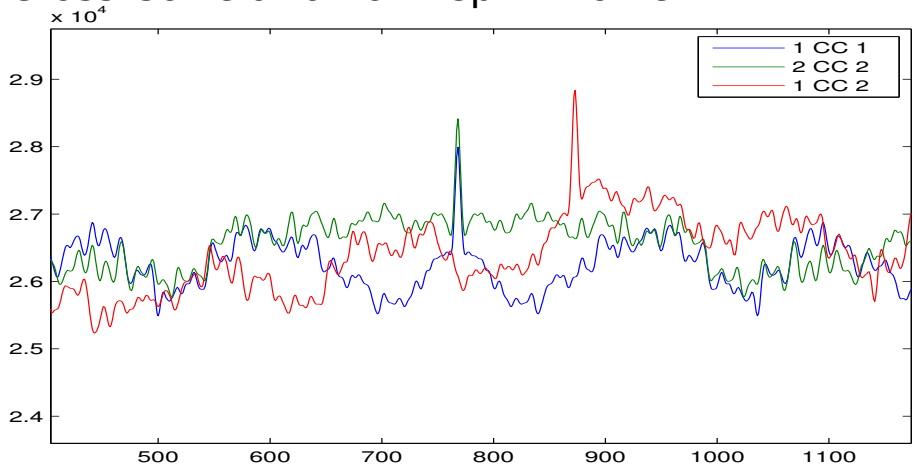
Component 1



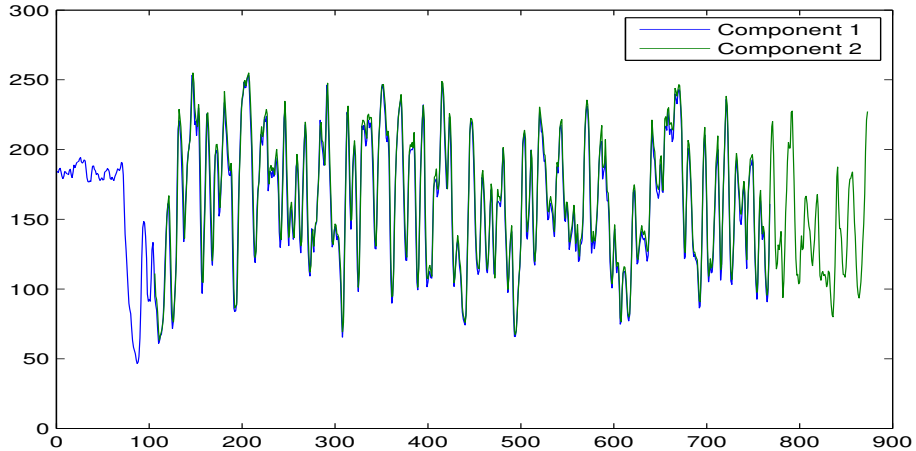
Component 2 (?)



Cross Correlation of Depth Profile



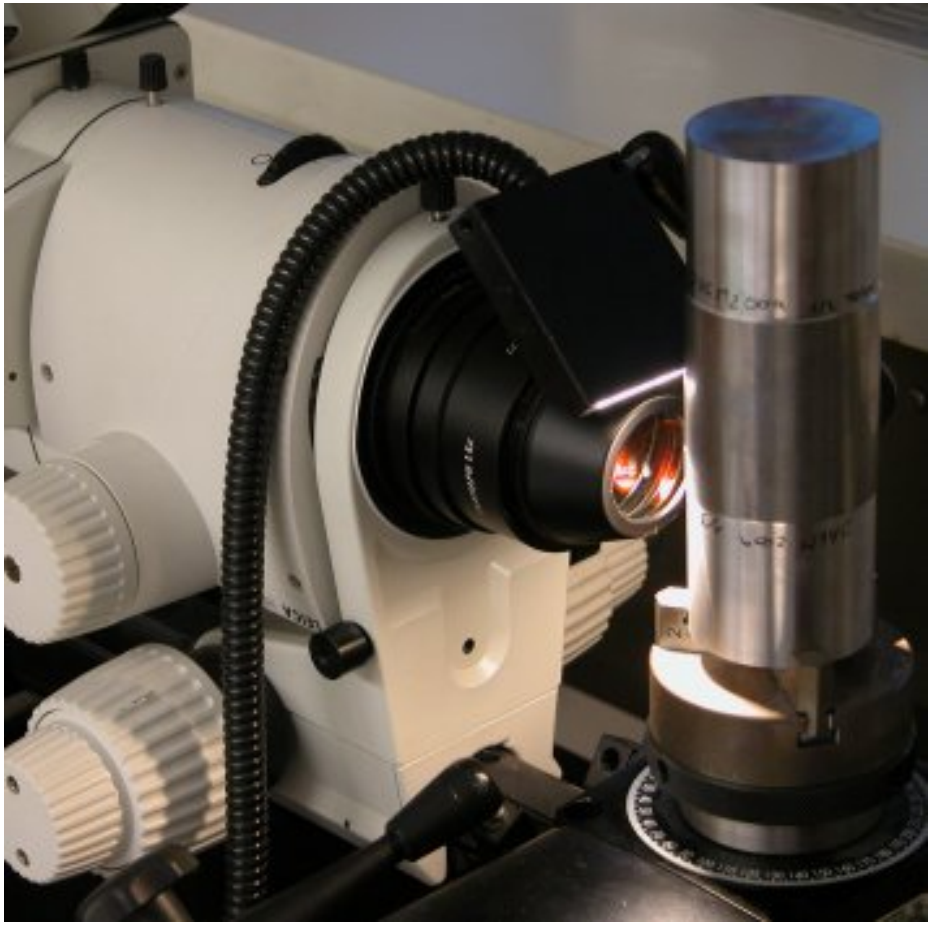
Shifted Normalized Profile

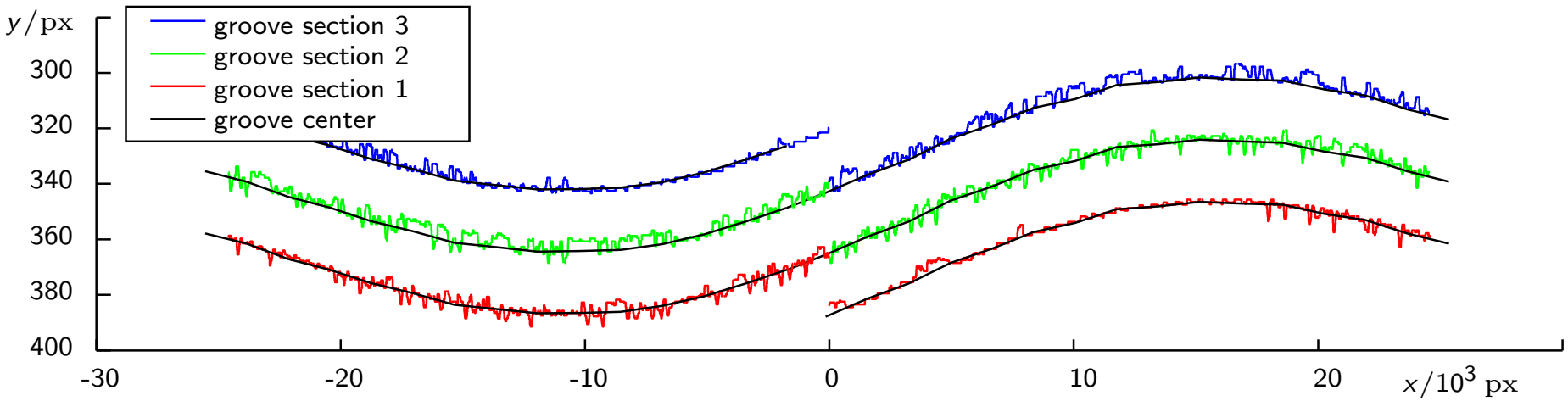


Reading out

Proceeding

- Microscope with low magnification ($2.6\,\mathrm{mm} \times 2\,\mathrm{mm}$)
- Images are stitched together using ≈ 100 views
- Overall surface view is partitioned using ≈ 200 cuts
- Groove sections are extracted and connected

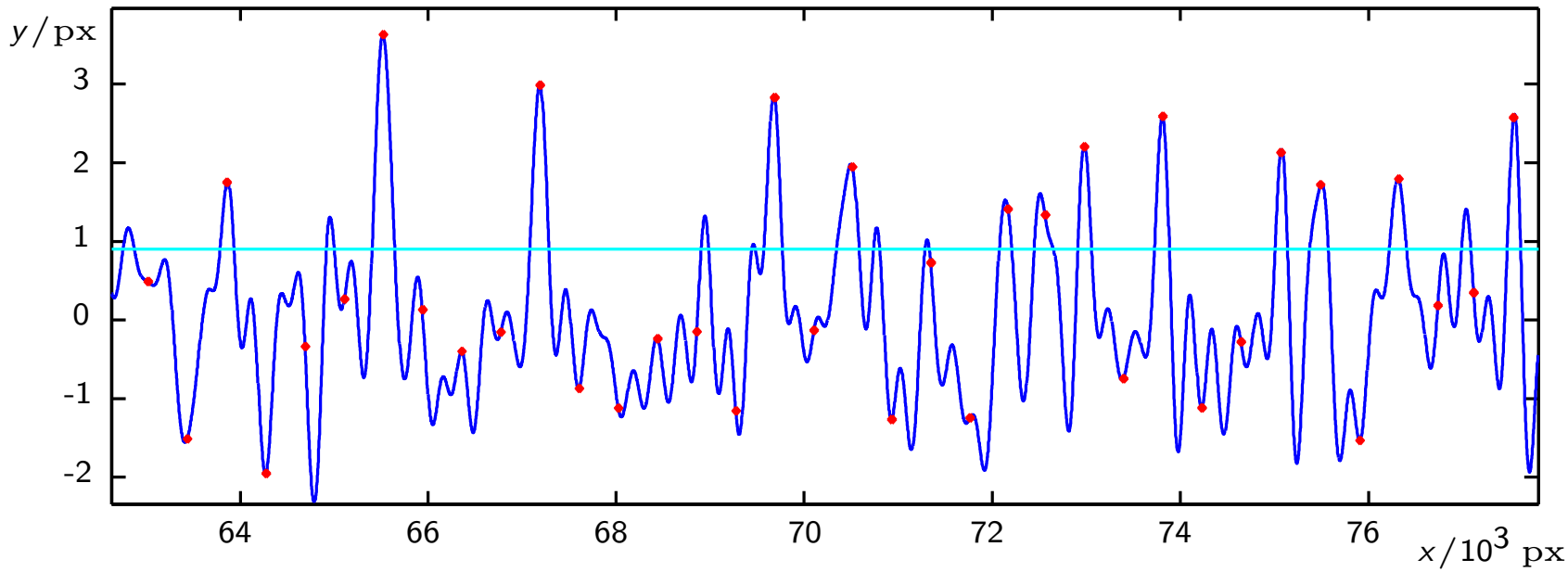




Run of the groove over one rotation

- Center of the groove wobbles (mechanical inaccuracies)
- Groove sections n and $n+1$ are fused
- Exacly one groove wound around the component
- Groove center is subtracted $\Rightarrow$ signal is available

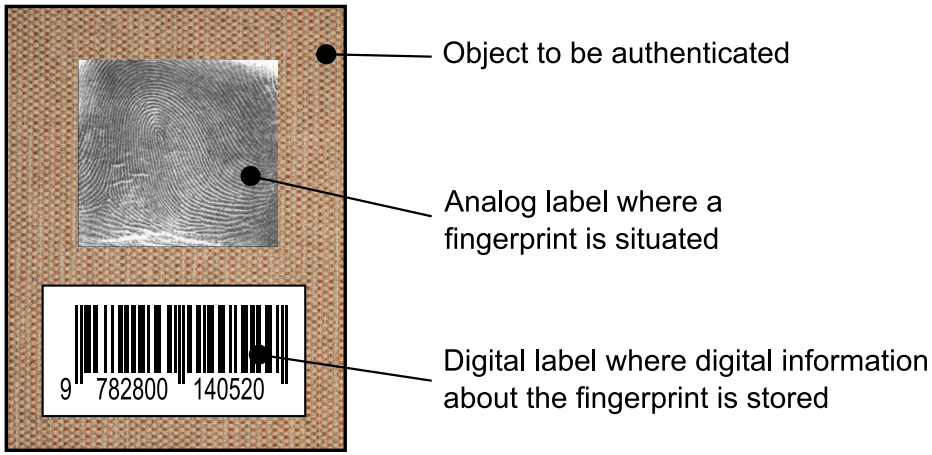
Self-Authentication in Gentelligent Components



- Inherent data storage and readout possible
  - Further error-correcting channel-code could be used
- Inherent fingerprint possible
  - Local disruptions can be overcome by using several grinding profiles

Conclusion

Conclusion



General idea

- Inherently store fingerprint in digital form
- Sign digital data with a public key

$\Rightarrow$ No prior information needed besides a root public key

Self-authentication in gentelligent components

- Groove ($6\,\mu\mathrm{m} \pm 3\,\mu\mathrm{m}$) on surface
- Reading: Directed illumination
- Data density of $1.6\,\mathrm{kbit/cm^2}$
- Fingerprint is grinding imprint
- Digital notation by sampled depth profiles

Data Density Calculation

Calculation

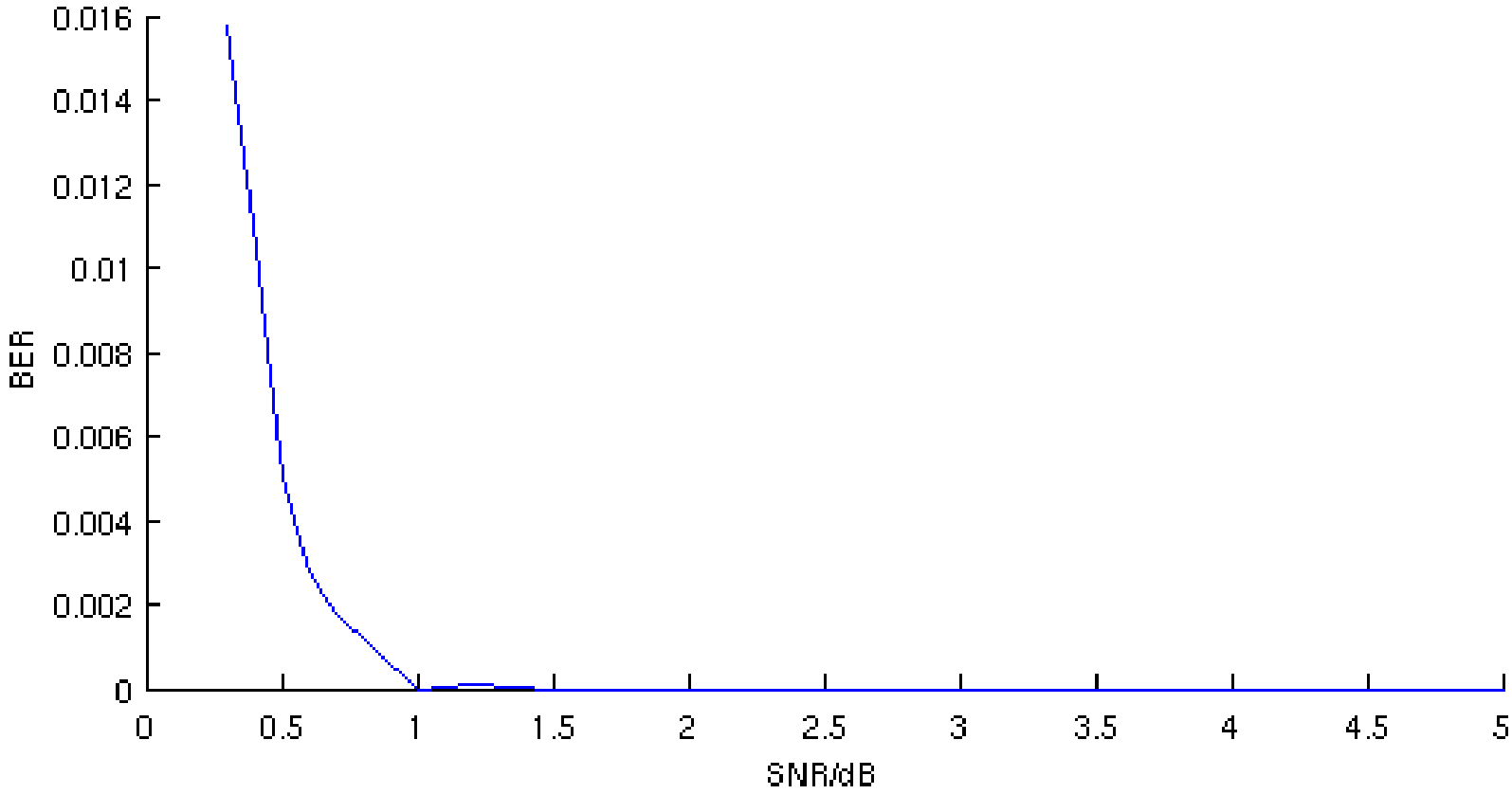
- 2-ASK: 1Bit/Symbol
- Data rate: $R = 1.1/\mathrm{mm}$
- Groove distance: $d_f = 0.07\,\mathrm{mm}$
- Density: $R \times \frac{1}{d_f} \approx 1.6\,\mathrm{kbit/cm^2}$

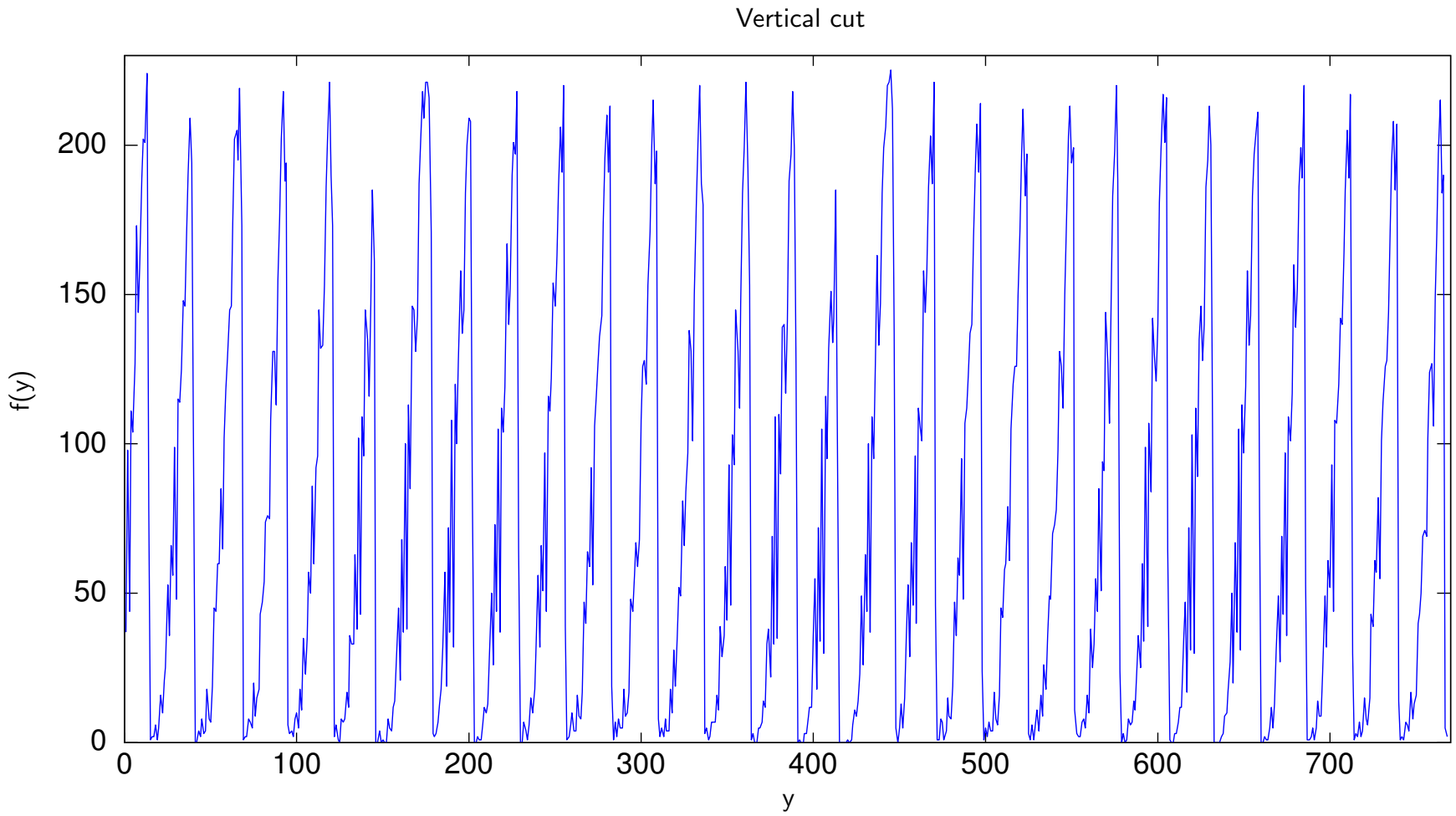
Not taken into account

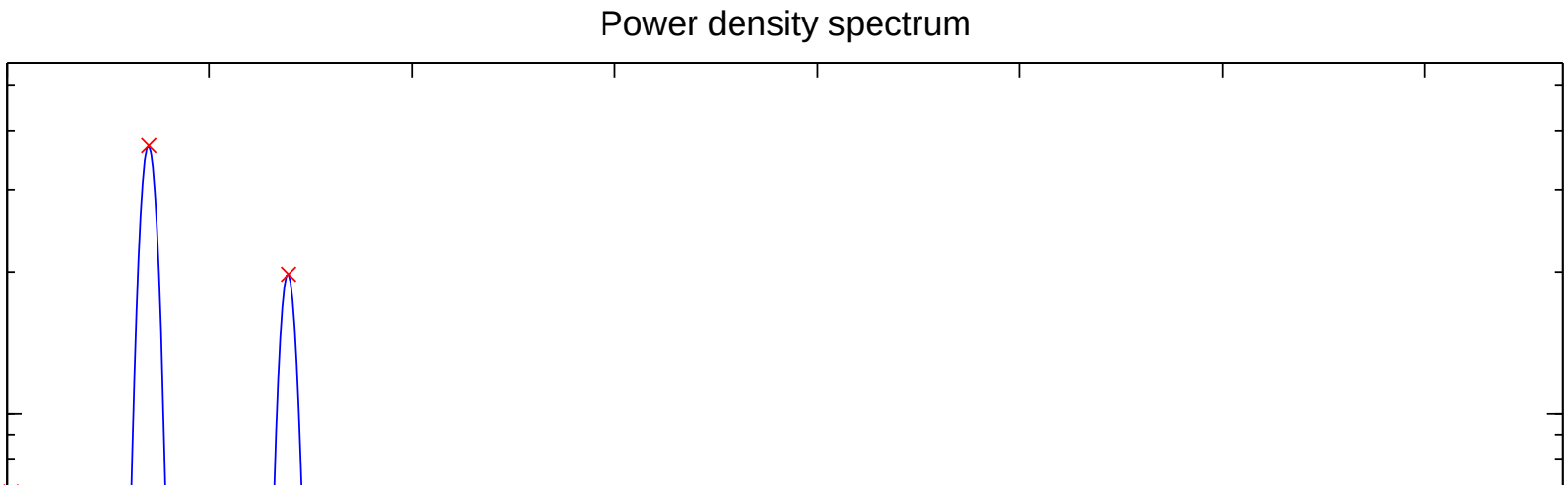
- Simplified demodulation
- Cross talking
- Redundancy for error correction
- Improved modulation scheme with multiple carriers

BER for Turbo Code

2/3 redundancy




Vertical cut
f(y)
y
0
50
100
150
200
0
100
200
300
400
500
600
700


Power density spectrum
10^3