Fast and precise nozzle line measurement for industrial digital printers: amplitude and phase estimation in undersampled nozzle patterns

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- Introduction in print quality control
- Evaluation of nozzle line patterns
- Presentation of new method for nozzle quality control (nozzle health)
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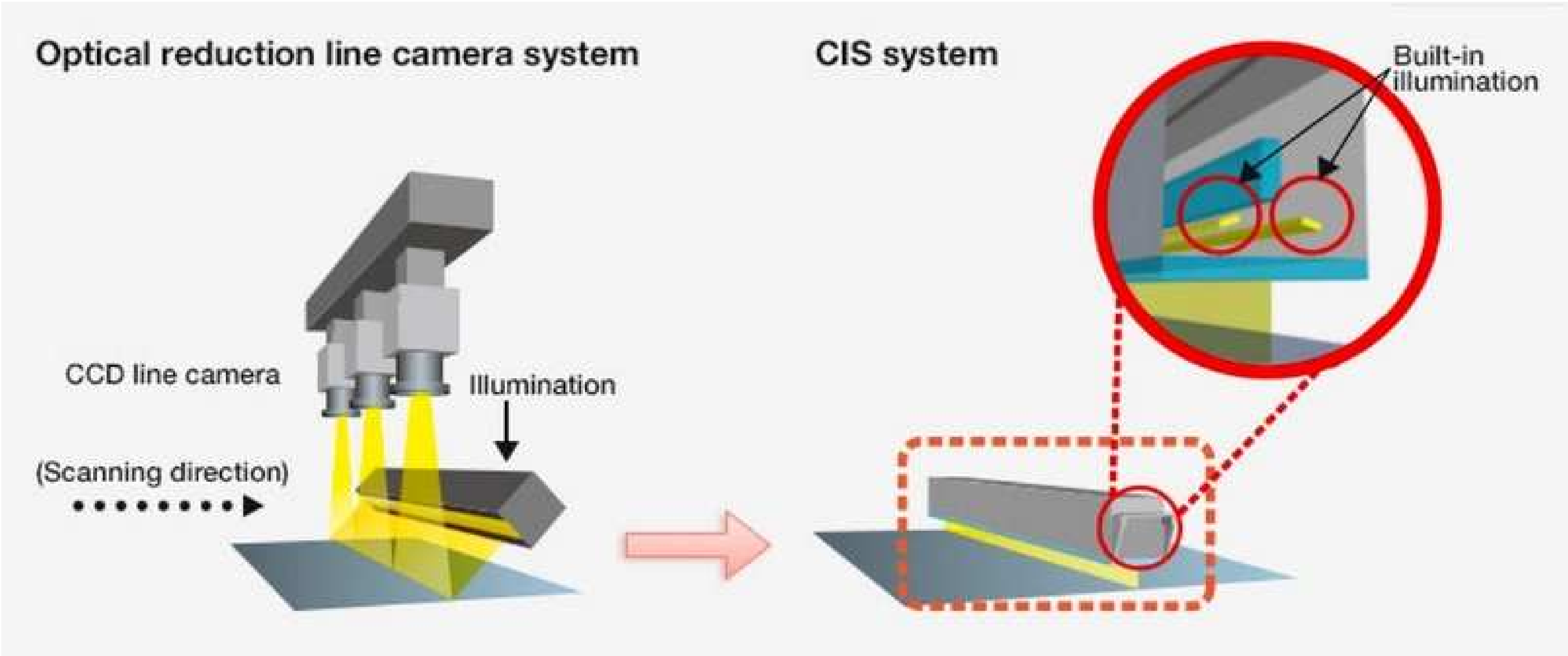
Scanning systems for print quality control

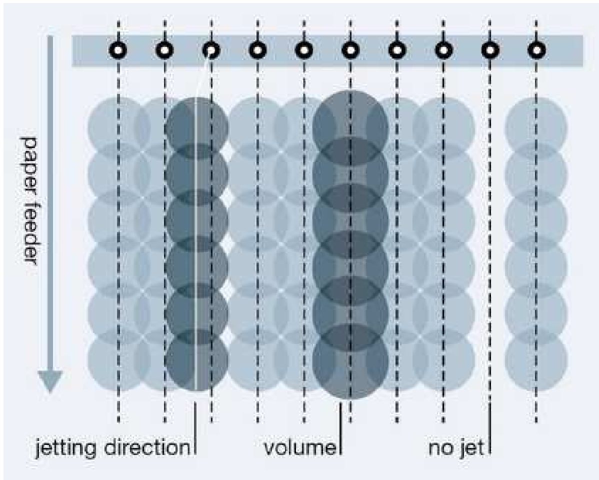


Source: Mitsubishi Electric

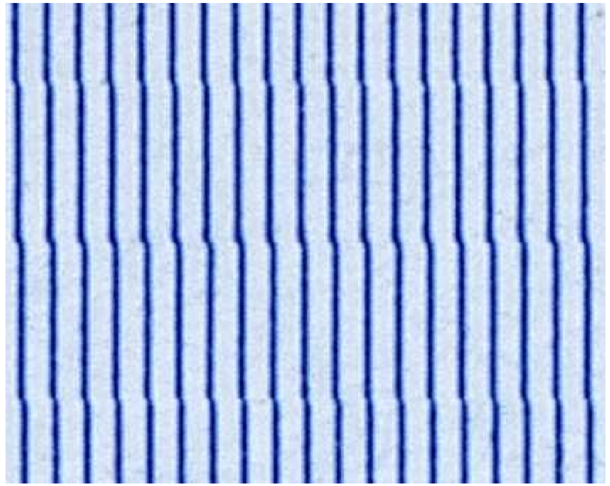
Industrial high-speed inkjet printing head SAMBA™

printing head (1200 dpi)

nozzle functionality



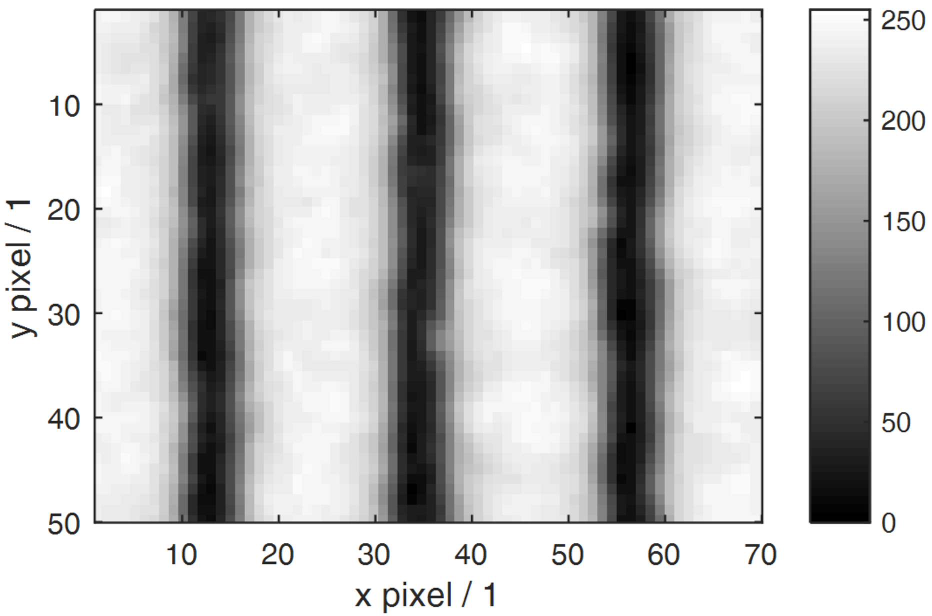
nozzle calibration pattern



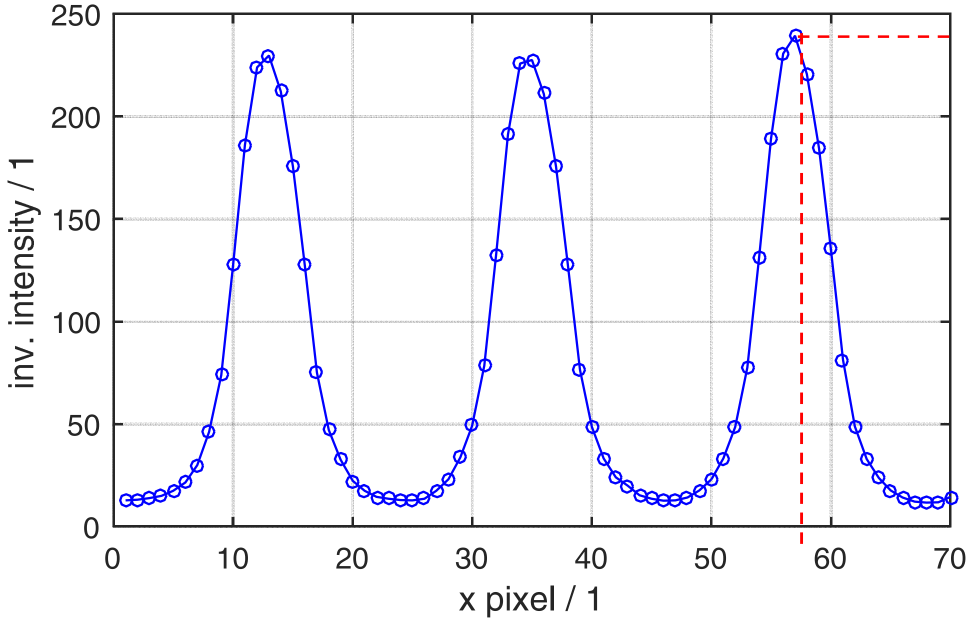
Source: FUJI

Evaluation of nozzle line pattern

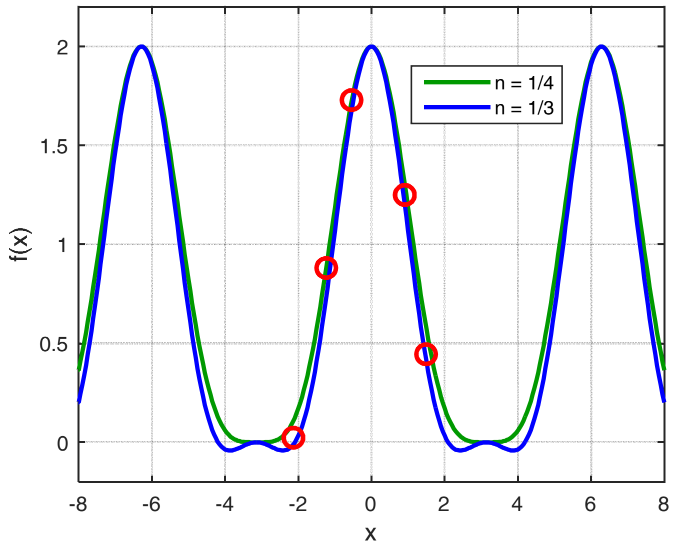
scan image

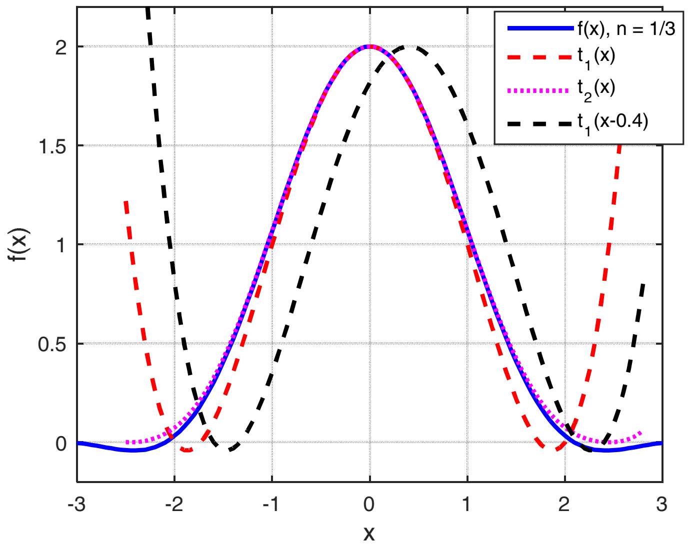


x-projection



Modelling of a nozzle line





$$f(x) = \cos(x) + \frac{1}{3}\cos(2x) + \frac{2}{3}$$

$$f(x) = \frac{2}{3}cos^2(x) + \cos(x) + \frac{1}{3}$$

$$T_1(x) = 1 - \frac{1}{2}x^2$$

$$t_1(x) = \frac{1}{6}x^4 - \frac{7}{6}x^2 + 2$$

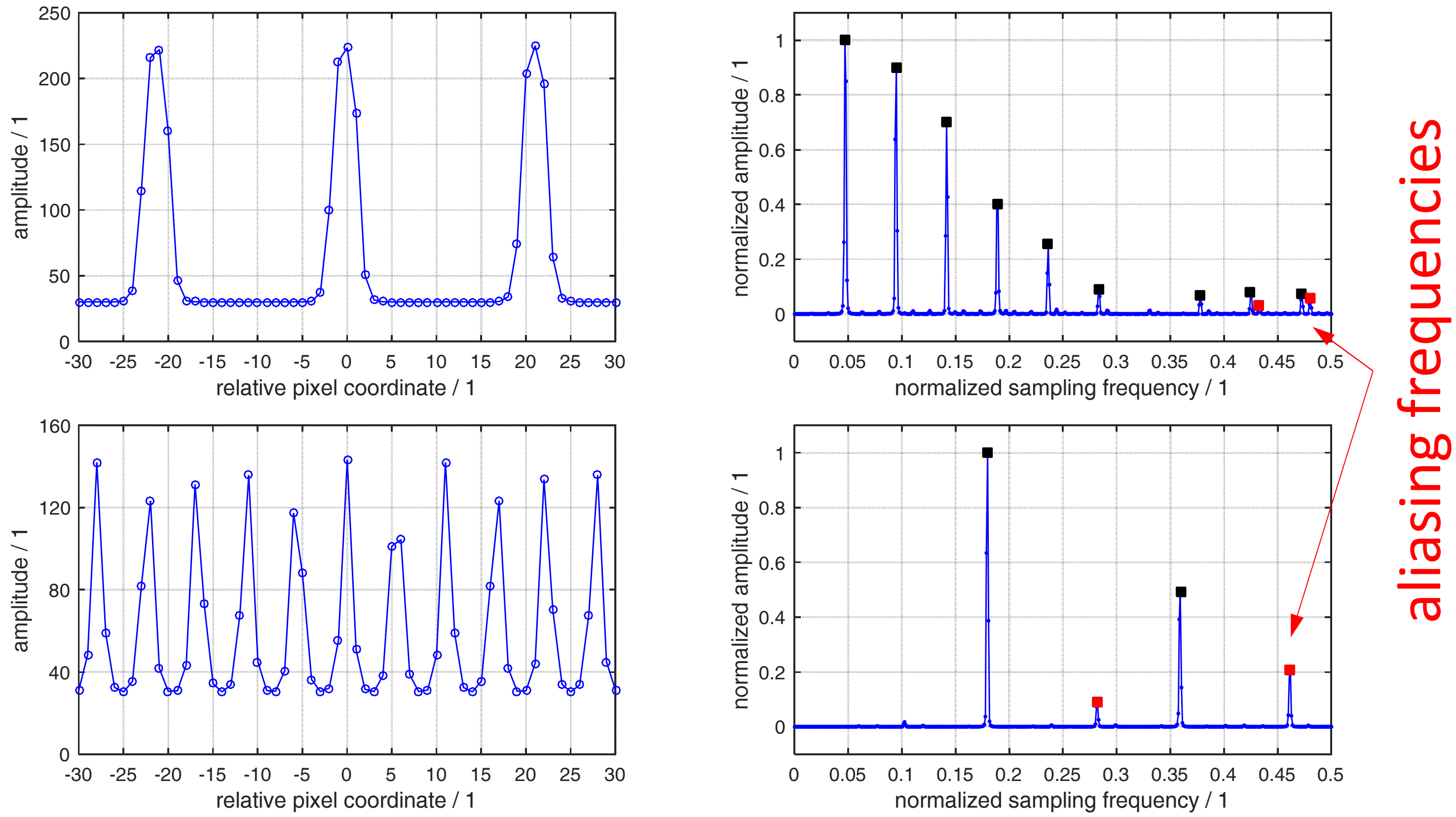
$$t_1(x-u) = \frac{1}{6}(x-u)^4 - \frac{7}{6}(x-u)^2 + 2$$

- Two component cosinus function assumed as a model function
- Good approximation in [-2; +2] using 1st degree Taylor polynomial for cos(x)
- Approximation function is a 4th order polynomial, 5 sampling points needed

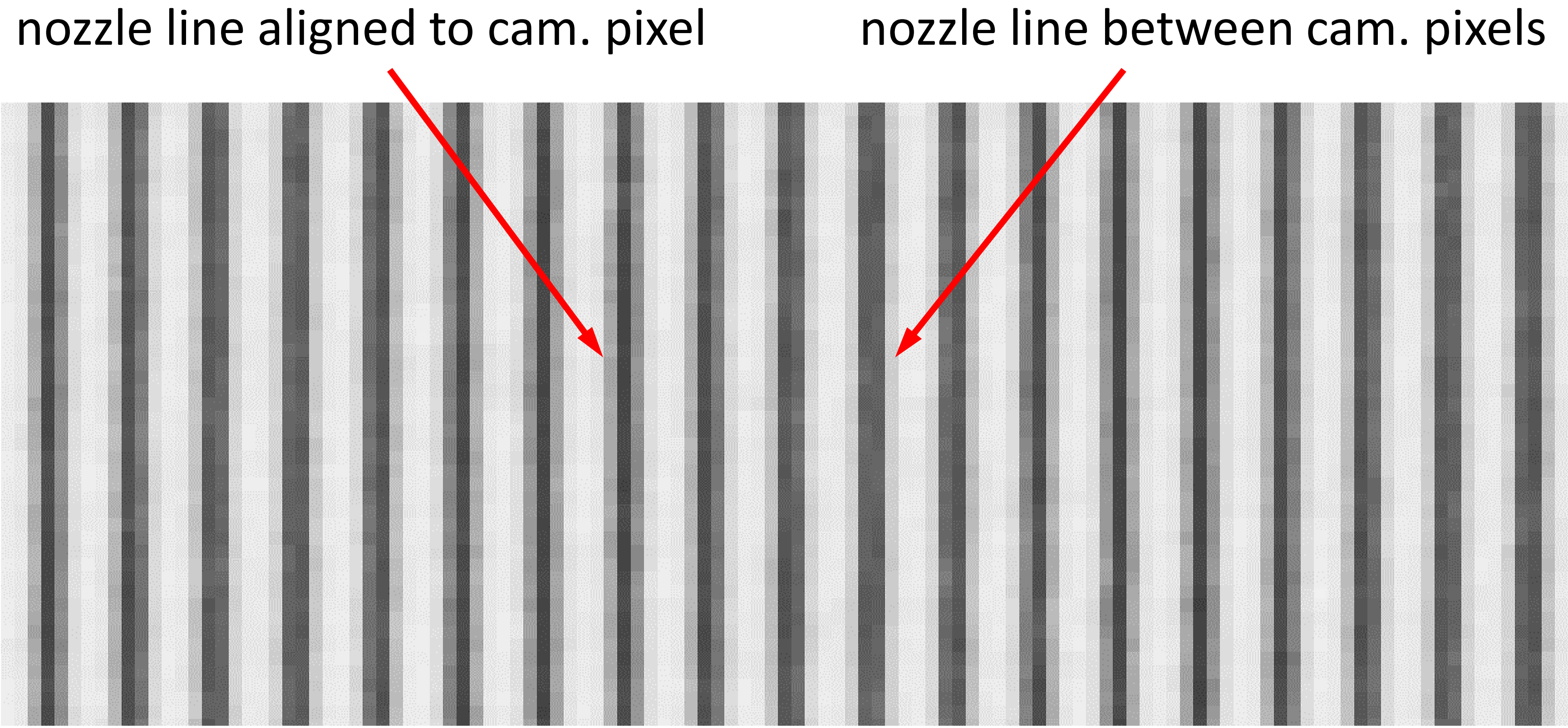
Spectral representation of nozzle line pattern

oversampled:
>20 samples
per period

undersampled:
6-7 samples
per period



Visual appearance of undersampled nozzle pattern



Solution based on the mathematical model

- Optimization criterion: first two harmonics of spectrum well separated from third harmonic and aliasing frequency, no aliasing frequencies btw. H1 and H2
- Solution 1: Using CIS - choose scanning resolution, optimize line distance
- Solution 2: Using line camera - set line distance, optimize scanning resolution
- Restrictions: Height of the nozzle calibration pattern, space on printing sheet

VARICIS Industrial Scanner

Our proven Industrial CIS Scanner

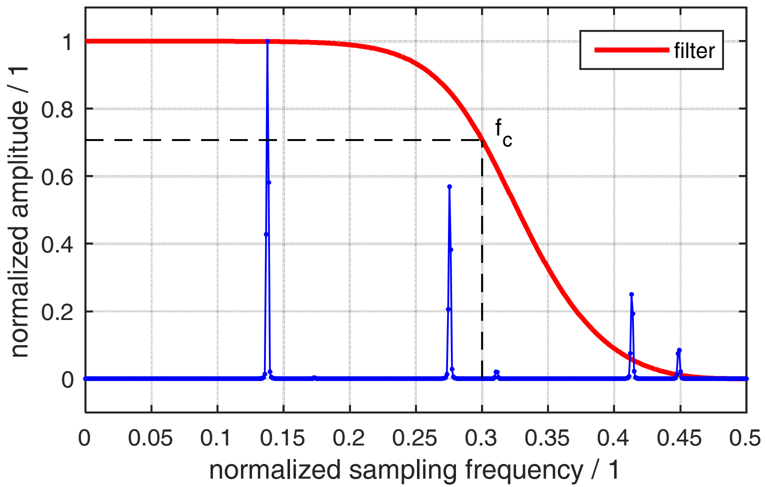
VARICIS COLOR/RGB

Resolution (dpi nom.)	Pixelsize (mm nom.)	Max. Line Rate (kHz) VSCIS Standard	VTCIS Turbo
300	0,085	10	30
400	0,063	3	18
600	0,042	6	18
1200	0,021	3	10

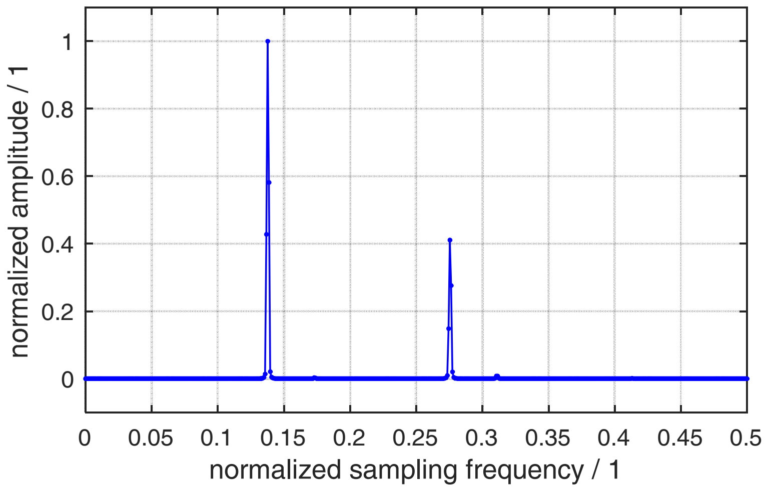
Piranha4 P4-CC-08K050
Bilinear Color Line Scan CMOS Camera

Filtering: Butterworth lowpass filter

before filtering



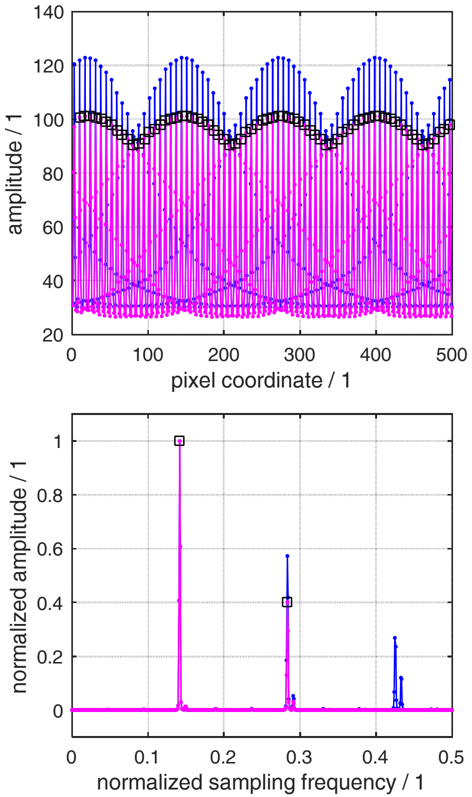
after filtering



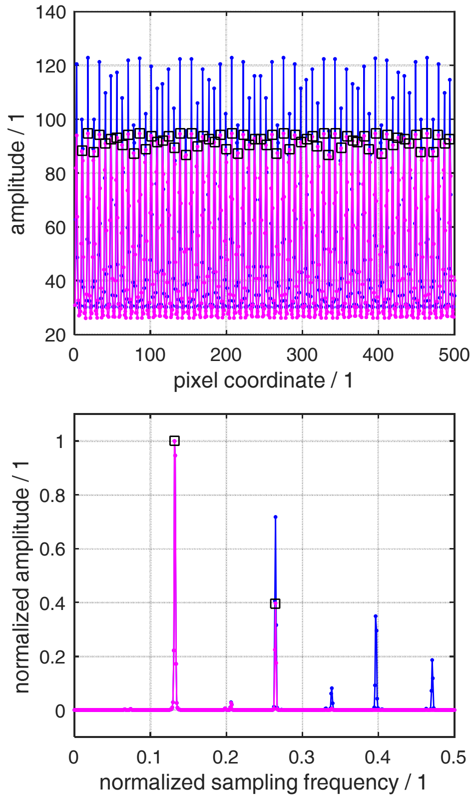
- Linear transfer function in the passband, practically distortion-free
- Set the cut-off frequency higher than the second harmonic frequency
- Adjust the cut-off frequency to optionally suppress the 2nd harmonic

Filtering: results for different line distancies

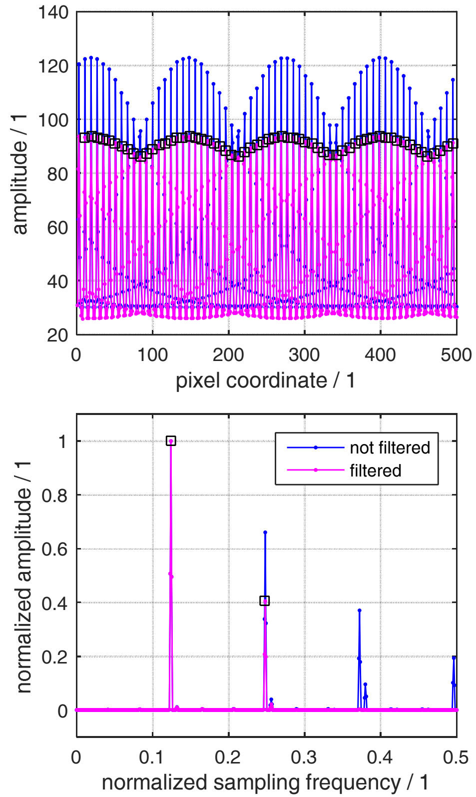
d = 14 pixel



d = 15 pixel



d = 16 pixel

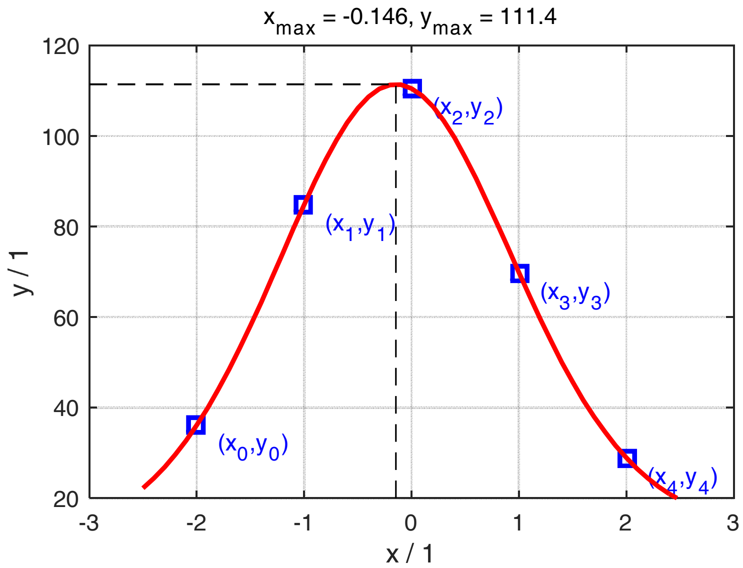


native print resolution = 1200 dpi

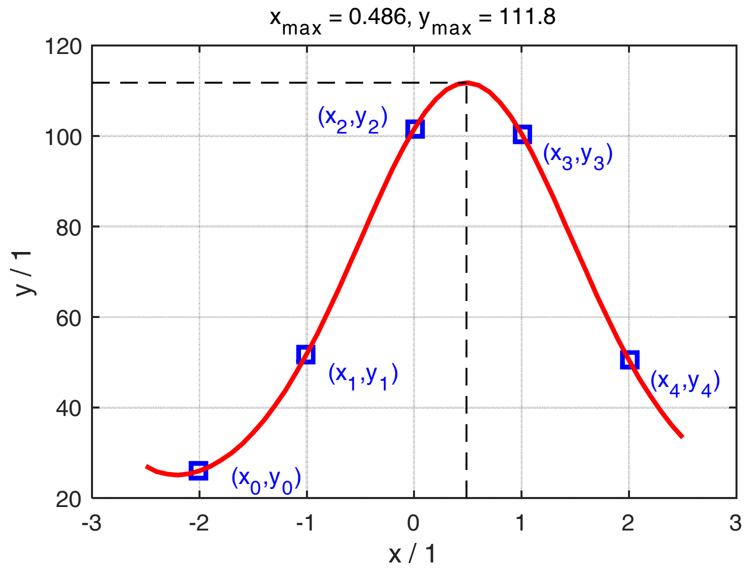
fixed scan resolution = 600 dpi

Amplitude and phase estimation

nozzle line aligned to cam. pixel



nozzle line between cam. pixels



- Two step solution:
- Step 1: Calculate the coefficients of the 4th order polynomial
- Step 2: Calculate the coordinates (phase, amplitude) of the local maximum

Amplitude and phase estimation

- Step 1: Calculate the coefficients A, B, C, D, E of the 4th order polynomial
- Step 2: Calculate the coordinates (phase, amplitude) of the local maximum
- Improvement: use natural logarithm of amplitudes

$$\begin{bmatrix} A \\ B \\ C \\ D \\ E \end{bmatrix} = \begin{bmatrix} x_0^4 & x_0^3 & x_0^2 & x_0^1 & 1 \\ x_1^4 & x_1^3 & x_1^2 & x_1^1 & 1 \\ x_2^4 & x_2^3 & x_2^2 & x_2^1 & 1 \\ x_3^4 & x_3^3 & x_3^2 & x_3^1 & 1 \\ x_4^4 & x_4^3 & x_4^2 & x_4^1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix}$$

$$f(x) = Ax^4 + Bx^3 + Cx^2 + Dx^1 + E$$

$$f'(x) = ax^3 + bx^2 + cx^1 + d = 0; \quad a = 4A, b = 3B, c = 2C, d = D$$

$$t^3 + pt + q = 0; \quad p = \frac{3ac - b^2}{3a^2}, q = \frac{2b^3 - 9abc + 27a^2 d}{27a^3}$$

$$t_k = 2\sqrt{-\frac{p}{3}} \cos\left(\frac{1}{3}\arccos\left(\frac{3q}{2p}\sqrt{\frac{-3}{p}}\right) - k\frac{2\pi}{3}\right); \quad k = 0,1,2$$

$$x_{max} = t_1 - \frac{b}{3a}, y_{max} = Ax_{max}^4 + Bx_{max}^3 + Cx_{max}^2 + Dx_{max}^1 + E$$

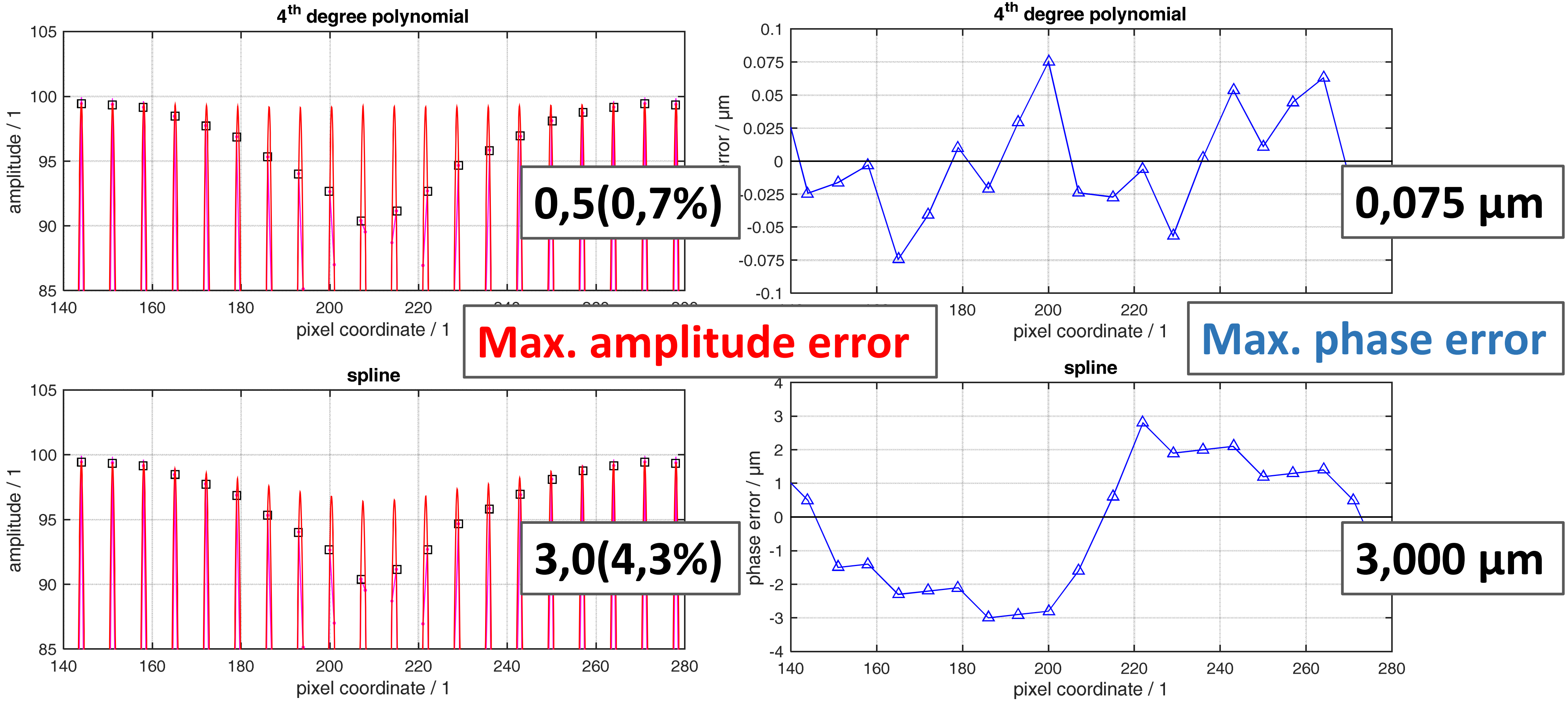
Improvement: $\exp(y_{max})$

Example:

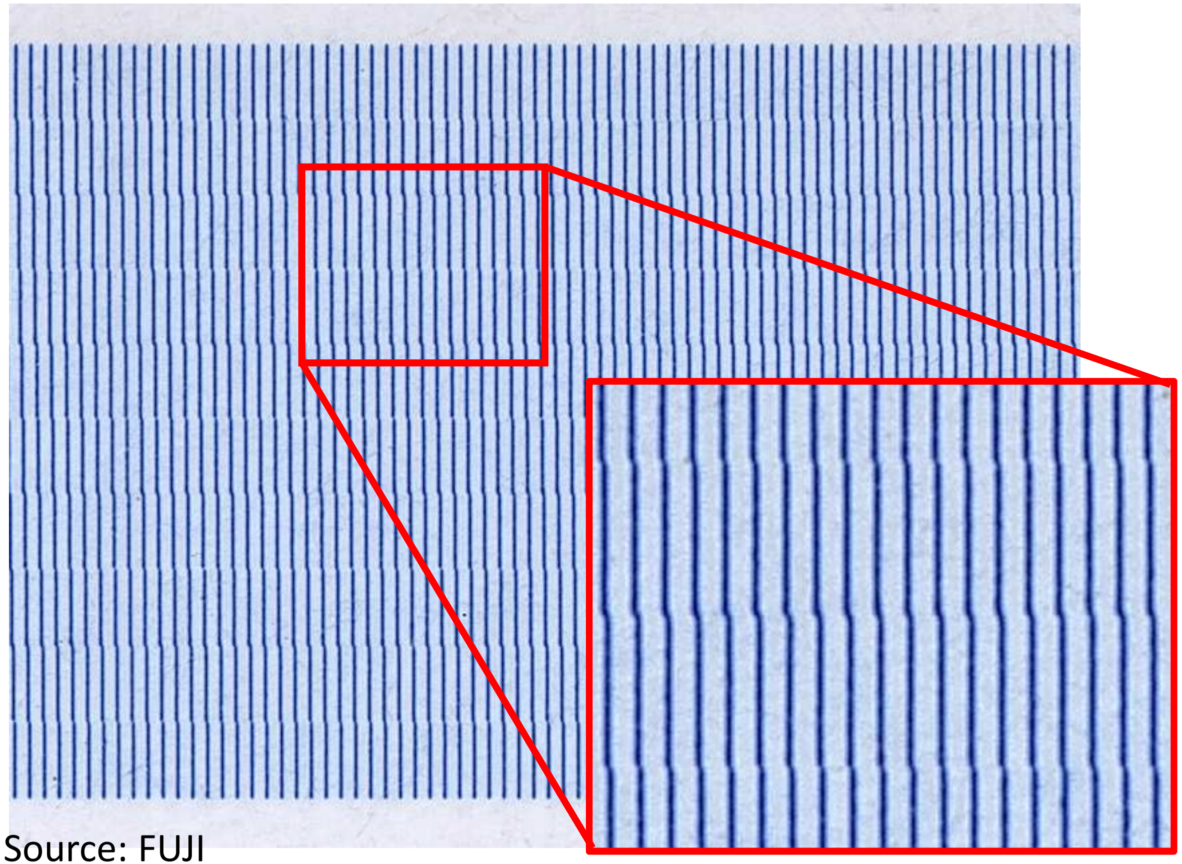
$$\begin{bmatrix} A \\ B \\ C \\ D \\ E \end{bmatrix} = \begin{bmatrix} +0.0416 & -0.1666 & +0.2500 & -0.1666 & +0.0416 \\ -0.0833 & +0.1666 & 0 & -0.1666 & +0.0833 \\ -0.0416 & +0.6666 & -1.2500 & +0.6666 & -0.0416 \\ +0.0833 & -0.6666 & 0 & +0.6666 & -0.0833 \\ 0 & 0 & +1.0000 & 0 & 0 \end{bmatrix} \begin{bmatrix} 56 \\ 116 \\ 174 \\ 112 \\ 45 \end{bmatrix} = \begin{bmatrix} +9.71 \\ -0.25 \\ -69.7 \\ -1.75 \\ +174 \end{bmatrix}$$

Improvement: $\ln(y_n)$

Comparison with alternative methods

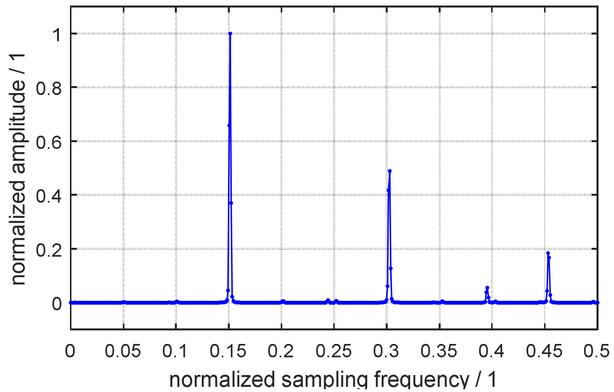


Solutions for FUJI JetPress 720S

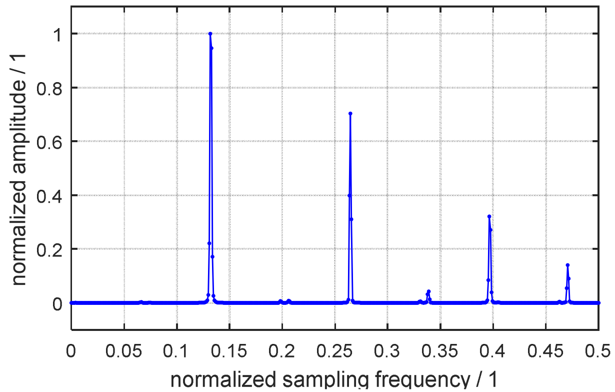


Source: FUJI

Line distance d = 10
Optimal resolution: 800 dpi



Resolution = 600 dpi
Optimal line distance: 15



Patent application DE102017222922A1

BIBLIOGRAPHISCHE DATEN DOKUMENT DE102017222922A1 (SEITEN: 16)			
INID	**Kriterium**	**Feld**	**Inhalt**
54	Titel	TI	[DE] Amplitudenwertberechnung
71/73	Anmelder/Inhaber	PA	Heidelberger Druckmaschinen AG, 69115,
72	Erfinder	IN	Bonev, Slavtcho, 67063, Ludwigshafen, DE
22/96	Anmeldedatum	AD	15.12.2017
21	Anmeldenummer	AN	102017222922
	Anmeldeland	AC	DE
	Veröffentlichungsdatum	PUB	19.06.2019

Compact description of method

Fast and precise nozzle line measurement for industrial digital printers

Fundamental method for amplitude and phase estimation in undersampled nozzle patterns

- Optimizing nozzle line distance: spectral evaluation
- Filtering: set cutoff frequency of Butterworth low-pass filter
- Polynomial fit: calculate coefficients of 4^{th} order polynomial
- Solution of reduced cubic: calculate amplitude (intensity) and phase (position) of nozzle line

Conclusions

The results has shown many advantages of our approach in comparison to conventional methods (for example: spline):

- Drastic shortening of execution time (up to 100x) compared to alternative solutions
- Calculation of reliable nozzle line amplitudes is now possible using mathematical model
- Calculation of nozzle line phases (coordinates) better than with alternative methods
- Real-time capability: fixed number of calculations (100 operations per nozzle line)
- Numerical stability: defined polynomial of the first derivative (reduced cubic with 3 real roots) with an exact solution
- Nozzle classification (skewed, weak) possible through coefficient analysis

Outlook

The new methodology represents a universal approach for inline nozzle quality control and is expected to find wide usage in future applications for industrial inkjet printing!

End of presentation

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