

Data Flow Analysis

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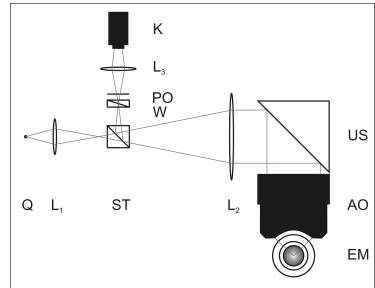
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 - Summary
 - Outlook

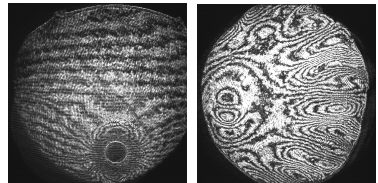
Optical modes

- refractive index $n=(\lambda, \rho, p, T)$
- temperature gradient \rightarrow density gradient \rightarrow refractive index gradient
 - variation of optical path length \Rightarrow interference: Wollaston shearing interferometry
 - deflection of beam: Schlieren/Shadowgraphy
- modular Wollaston shearing interferometer works as Schlieren/Shadowgraphy

K: Camera, L: Lenses, PO: Polarizer, W: Wollastonprism, Q: Laser, ST: Beam Splitter, US: Tilted Mirror, AO: Optical Adaption, EM: Sphere

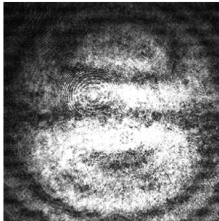
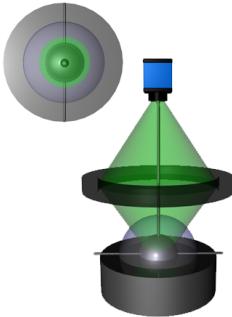


scetch of ray path

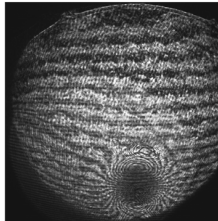
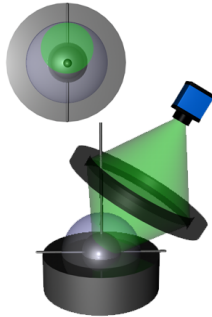


interferograms

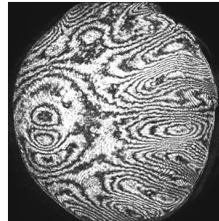
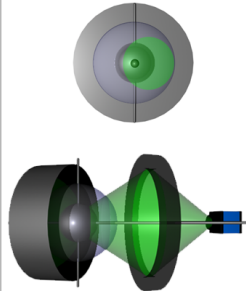
SRM



EC standalone



EC integrated in FSL

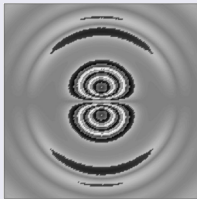


Motivation of image improvement

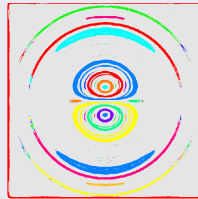
- variations of temperature differences causes different fringe pattern
 - ⇒ fluid analysis: select and extract relevant fringe pattern
- base for calculation the temperature field
- difficulty: noise in experimental images

Application to numerical images

- no negative effects in numerical images (no noise)
- prediction of fringe pattern in experimental images with special experimental parameters



numerical image



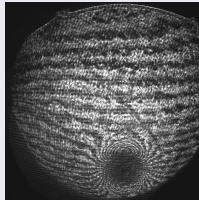
different operations



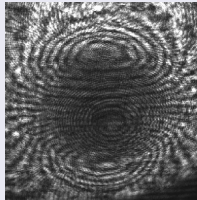
binary image

Application to experimental images

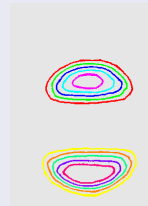
- negative effects (noise) \Rightarrow hard images improvement
- comparison with numerical results



experimental image



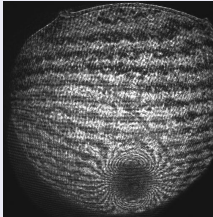
different operations



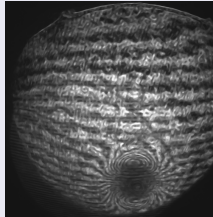
binary image

Filtering step

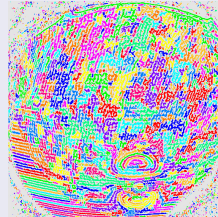
original



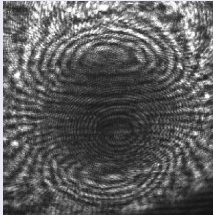
median



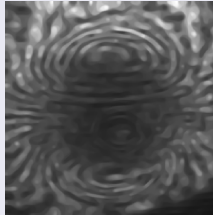
regions



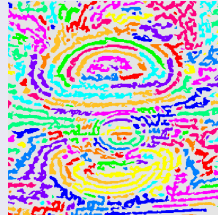
raw



smoothed



labeled



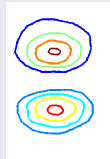
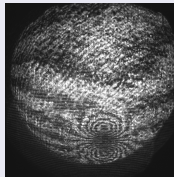
Motivation of image processing

- Inverse modelling \Rightarrow processing temperature field from interferogram
- calculation of absolute temperature

Interferogramm → Temperature Field

- experimental interferogram → calculation of integrated temperature curve
- comparison with numerical data

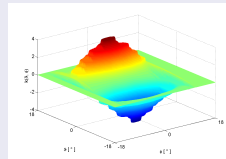
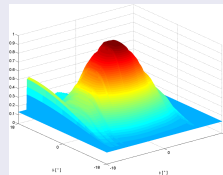
interferogram



selected fringe pattern



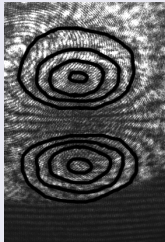
integrated temp. field



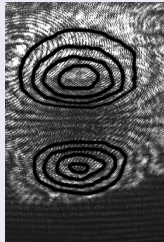
phase shift

Fringe pattern selection: manual

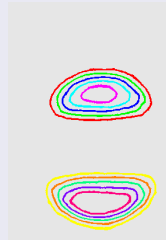
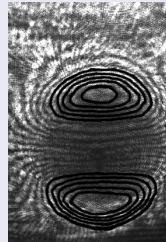
$\Delta T = 4 \text{ K}$



$\Delta T = 6 \text{ K}$



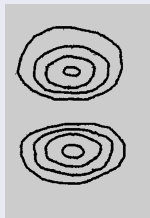
$\Delta T = 8 \text{ K}$



Calculation of temperature field

fringe pattern

$\Delta T = 4 \text{ K}$



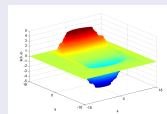
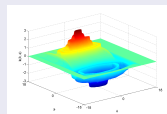
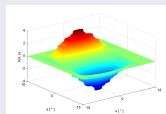
$\Delta T = 6 \text{ K}$



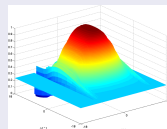
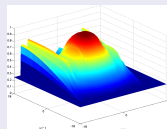
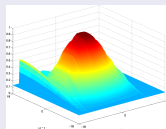
$\Delta T = 8 \text{ K}$

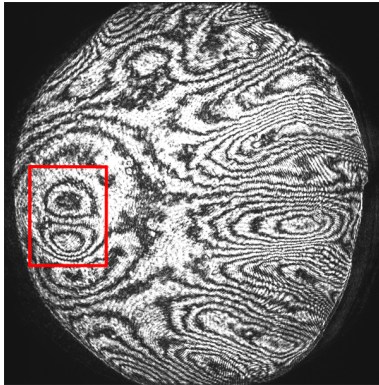


phase shift



temperature field





original image



relevant region

$$\Delta T = 7 \text{ K}, n = 2 \text{ Hz}, V_{rms} = 10 \text{ kV}$$

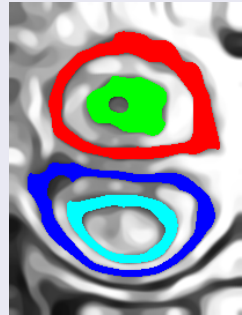
Fringe pattern selection: automatic



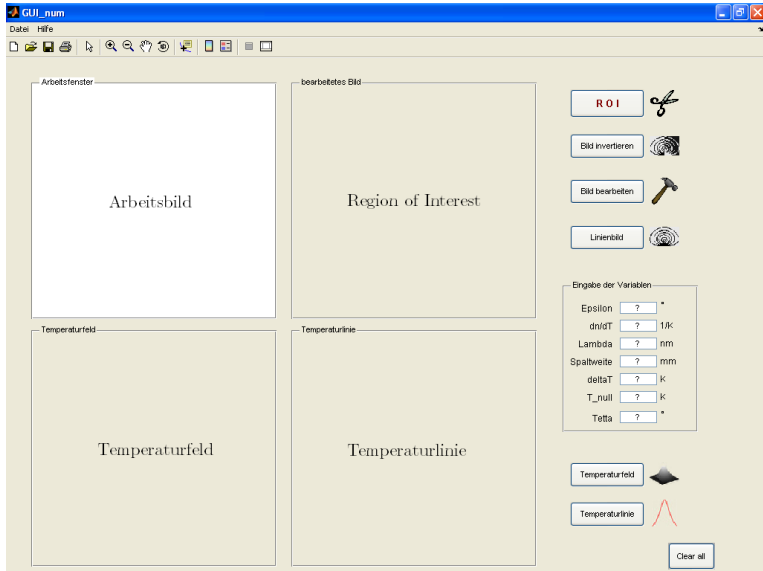
relevant region

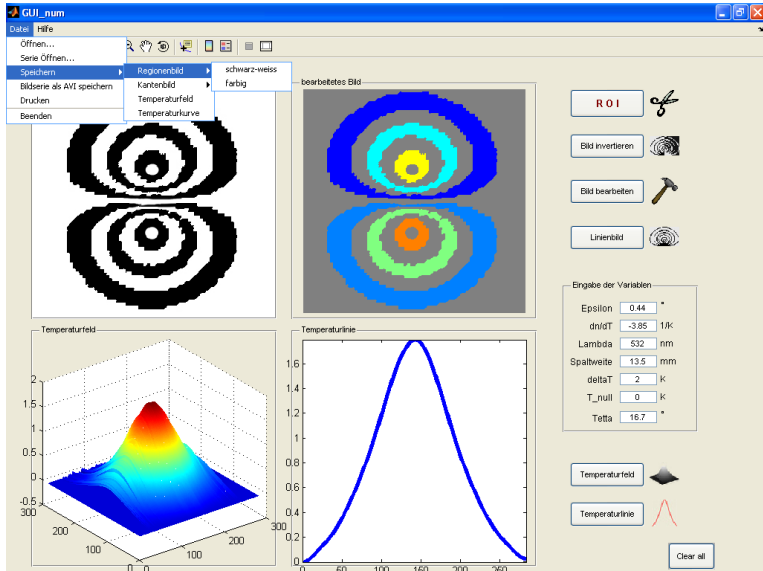


median filter



selection



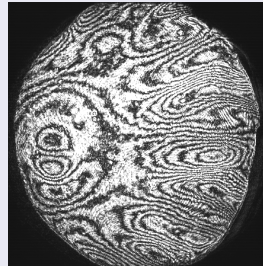
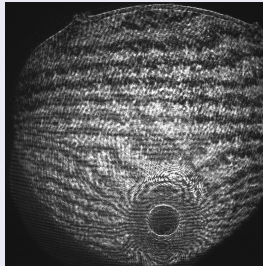


Summary

- Image improvement: selecting fringe pattern
- Image processing: inverse modelling
⇒ fringe pattern extraction ⇒ calculation of intergrated temperature field

Outlook

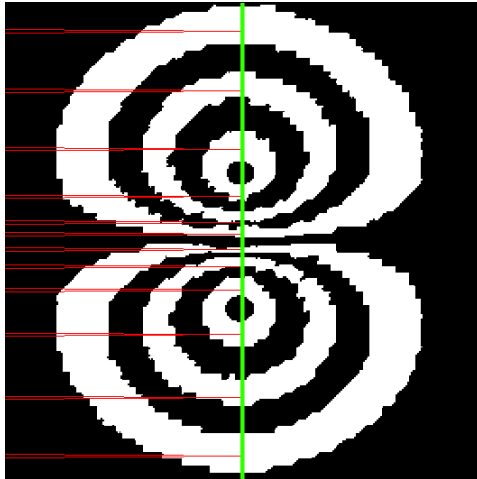
- effective and automatic fringe pattern selection
⇒ comparison with numerical data
- transfer to more complex pattern

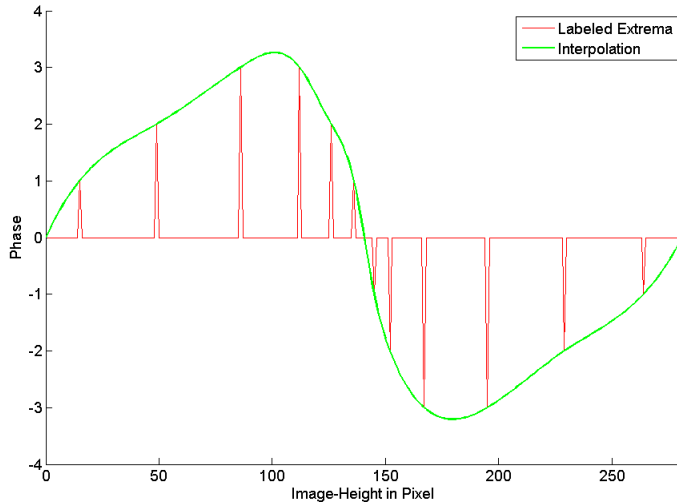


- algorithm for analysing Shadowgraphy and Schlieren
- upgrade existing Graphical User Interface

Thank you for your attention!

Appendix





⇒ getting temperature function by integration of the function (green)

Integration

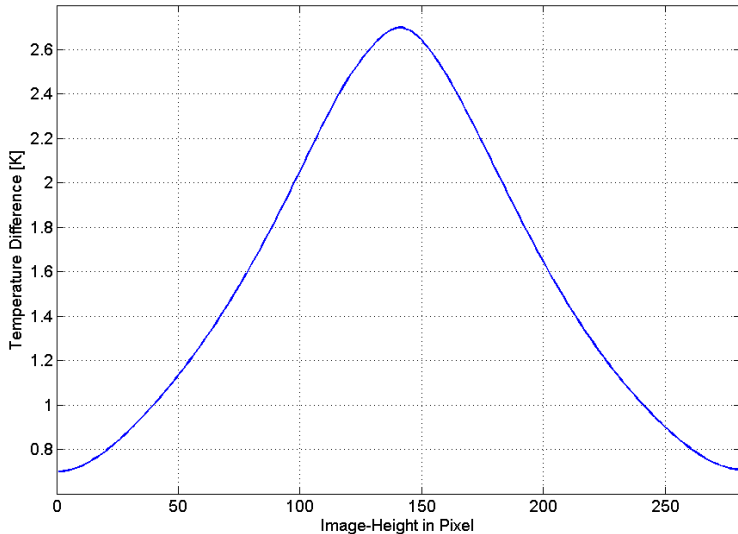
Formula

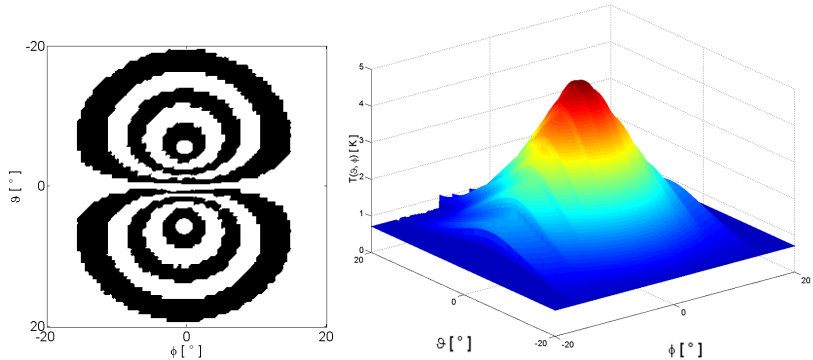
$$\begin{aligned}
 T(\vartheta_1, \varphi) &= \int_{\vartheta_0}^{\vartheta_1} \frac{\partial T(\vartheta, \varphi)}{\partial \vartheta} d\vartheta + T_0 \\
 &= \frac{\Delta \vartheta \lambda}{2d \varepsilon_{A/B} (dn/dT)} \int_{\vartheta_0}^{\vartheta_1} f_{\text{phase}}(\vartheta, \varphi) d\vartheta + T_0
 \end{aligned}$$

Variables

Scaled prism angle:	$\varepsilon_{A/B}$	=	0.44°
Wavelength:	λ	=	$532 \times 10^{-9} m$
Axial angle:	ϑ	=	16.7°
Gap:	d	=	$13.5 \times 10^{-3} m$
Temperature difference:	ΔT	=	$2K$
Variation of refractive index:	(dn/dT)	=	$-3.85 \times 10^{-4} K^{-1}$
Start value:	T_0	=	$(0.351 \times \Delta T)K$

Results of integration - temperature function





Integration of temperature field on numerical interferogram