Computational Laser Metrology

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MST

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

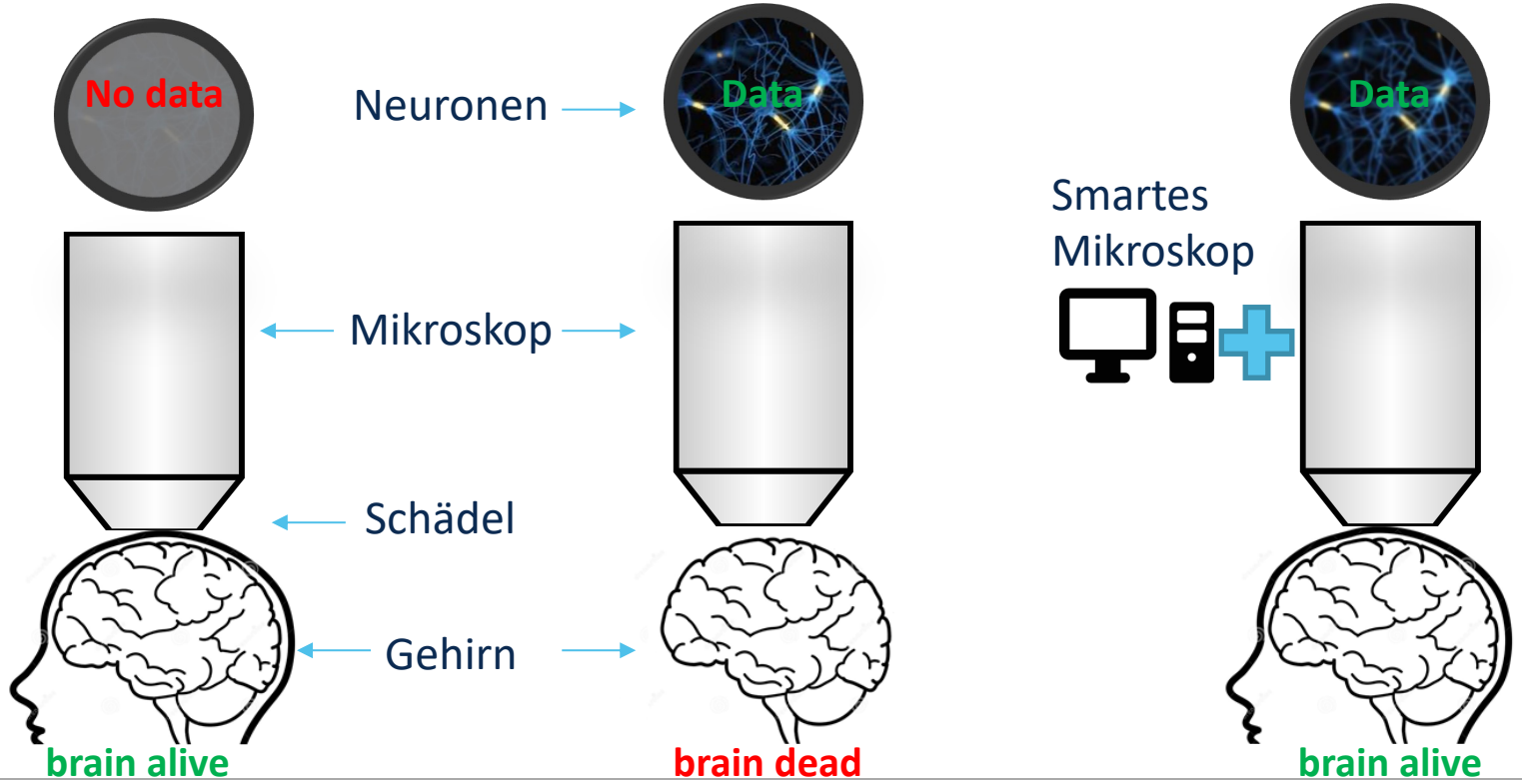
Aim of computational laser metrology

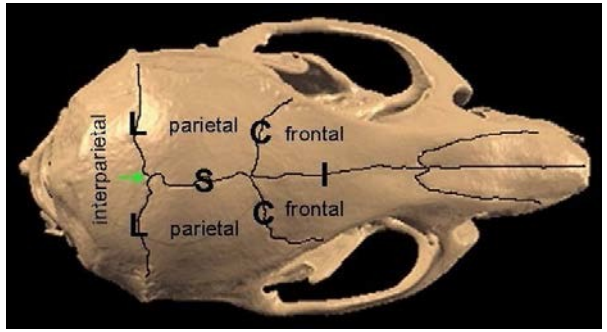
3D imaging through complex media (example focusing through mouse skull)

Problem:
Light scattering in the cranial bone

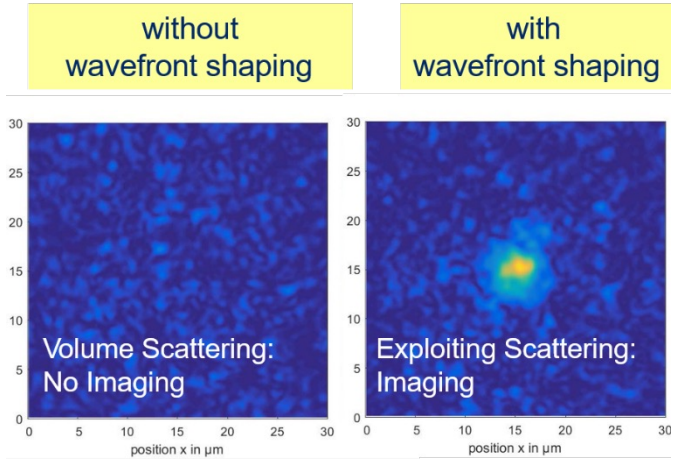
State of the Art:
Kill mouse and remove skull

Proposal:
Smart Microscope





Skull provided by Moritz Kreysing (MPI-CBG)

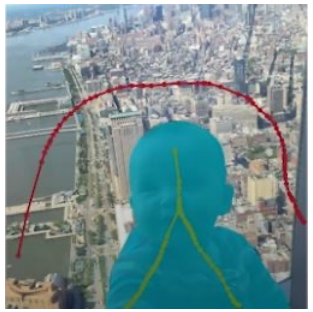


→ generation of focus through a skull
~ 400 µm thickness

3. Semester: Neuronale Netze in der Bildverarbeitung für die Sensorik und Messtechnik" (0/2/0)

Aufgaben der rechnergestützten Bildverarbeitung

Segmentierung / Erkennung

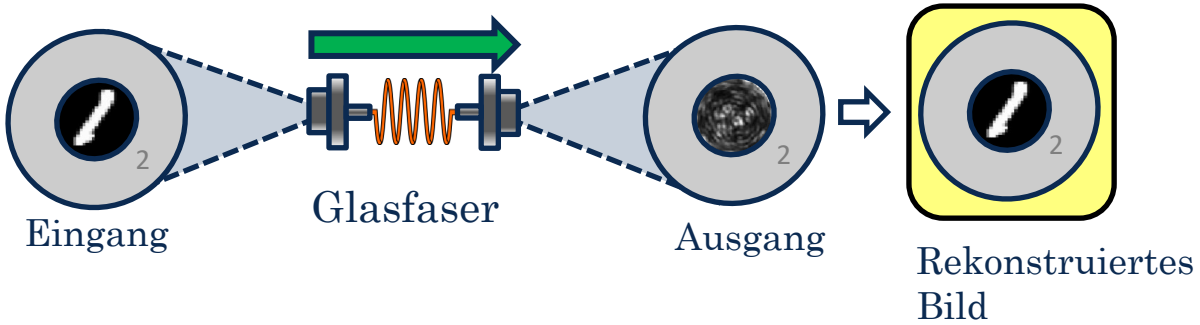


1

Analyse

1

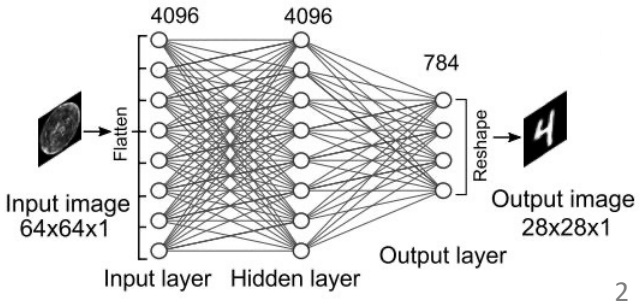
Rekonstruktion



Methoden

Implementierung von Algorithmen ⇨ MATLAB [3]

Trainieren Neuronaler Netze



2

- ⇨ Grundlagen
- ⇨ Architekturen
- ⇨ Trainingsdaten

Betreutes Computerpraktikum

Werkzeuge

Messunsicherheit

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(\Gamma_i - \bar{\Gamma})^2}$$

Korrelation

$$\Gamma = \frac{\sum_m \sum_n (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{(\sum_m \sum_n (A_{mn} - \bar{A})^2)(\sum_m \sum_n (B_{mn} - \bar{B})^2)}}$$

Voraussetzungen: Grundlagen Mathematik/Informatik
Es wird eine Einführung in MatLab und Neuronale Netze gegeben

1 https://www.youtube.com/watch?v=oIBl0KIMpAo
2 Zhu, Changyan, et al. "Image reconstruction through a multimode fiber with a simple neural network architecture." Scientific reports 11.1 (2021): 1-10.
3 https://de.wikipedia.org/wiki/Matlab

Structure

Grundlagen (1/3/1):
- 3. Semester: Neuronale Netze in der Bildverarbeitung (0/2/0)
- 4. Semester: Messtechnik I: Grundzüge des Messens (1/1/0)
- 4. Semester: Messtechnik Praktikum (0/0/1)

Vertiefung – Pflicht (6/4/0)
- 5. Semester: Messtechnik II: Mess- und Sensortechnik (2/1/0)
- 5. Semester: Digitale Holographie und Bildverarbeitung (1/1/0)
- 6. Semester: Messtechnik III: Messsystemtechnik (1/1/0)
- 6. Semester: Lasermesstechnik (2/1/0)

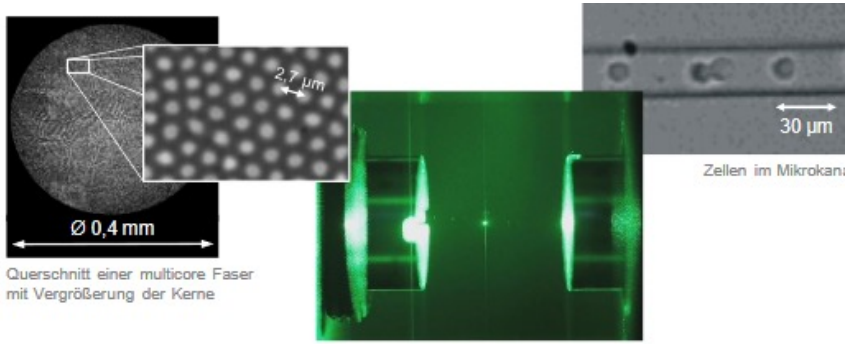
Vertiefung – Wahlpflicht (2 SWS):
- 5. Semester: Biomedizinische Systemtechnik und Optogenetik (1/0/0)
- 5. Semester: Lasermesssysteme für die Fluidtechnik (2/0/0)
- 5. Semester: Projekt Photonische Messsystemtechnik (0/1/0)
- 5./6. Semester: Oberseminar Messsystemtechnik (0/2/0)
- 6. Semester: Mechatronische Lasersensoren (2/0/0)
- 6. Semester: Praktikum Lasersensorik (0/0/1)

Lasermesstechnik (2/1/0), 6. Semester

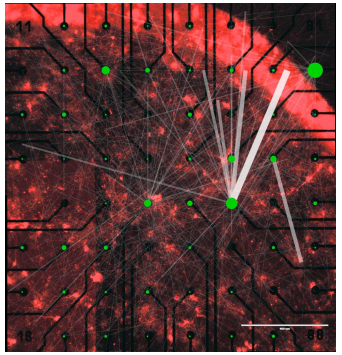
Grundlagen von Lasermessverfahren

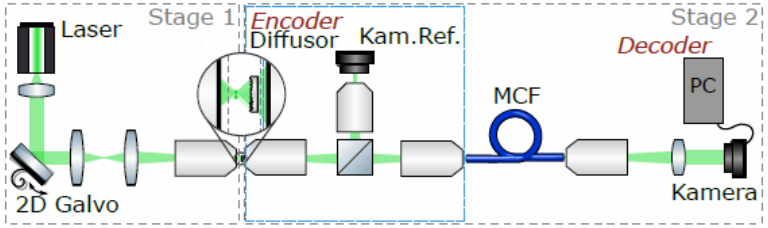
Benotung: mdl. Prüfung 15 min,
zusammen mit Holographie: 25 min

Optische Pinzette zur Rotation von Zellen in einem Mikrokanal



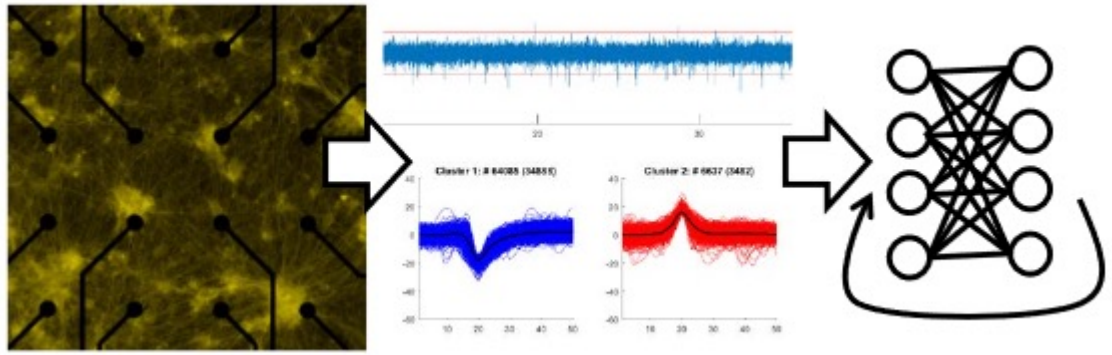
Biomedizinische Systemtechnik und Optogenetik (1/0/0), 5. Semester





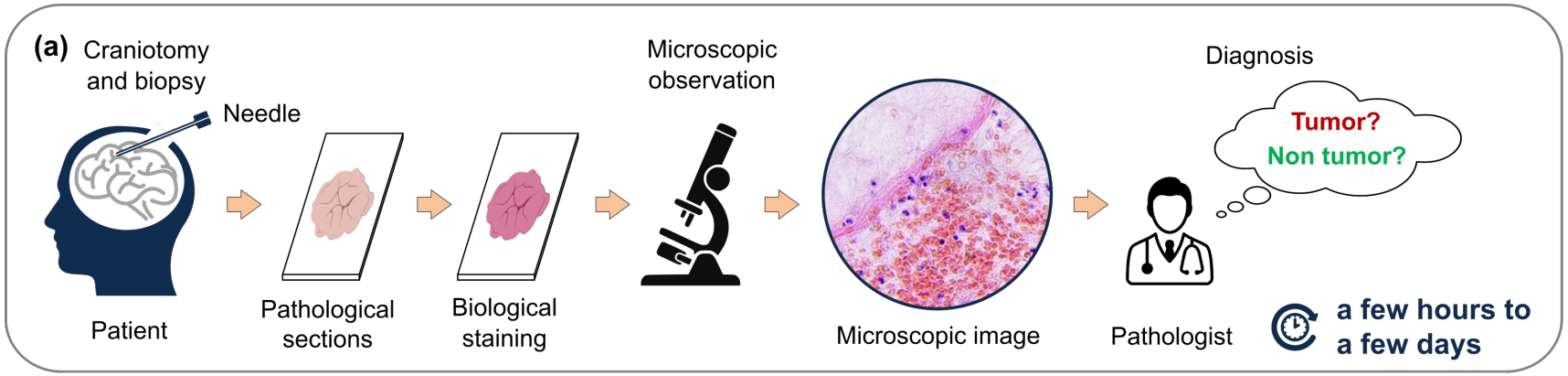
Left: connection in human neural network,
right computational lensless endoscope

Analyse organischer neuronaler Netze mit künstlichen neuronalen Netzen



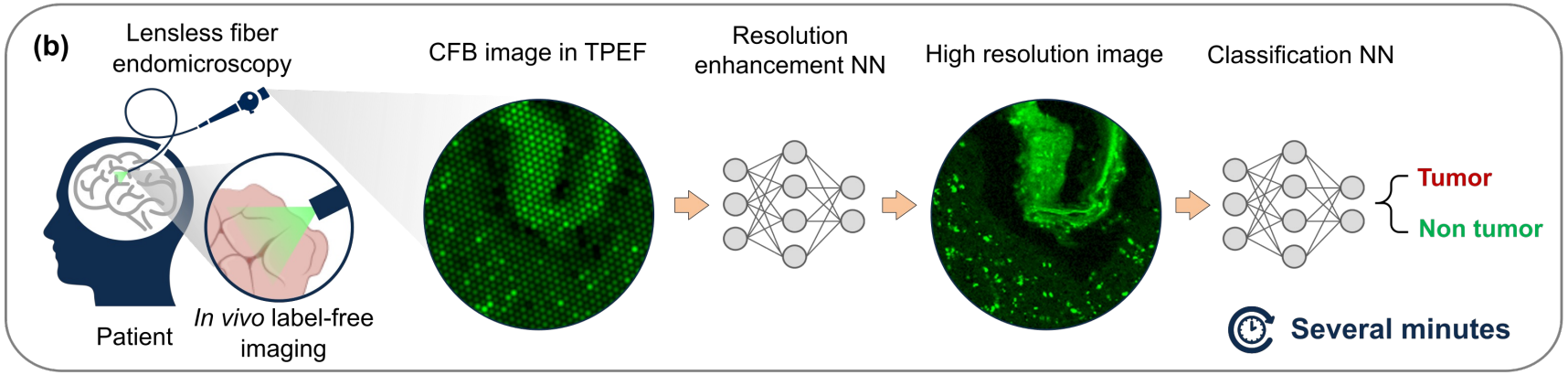
BrainAce: AI-based cancer diagnosis using endoscopy

State of the art: pathological biopsy for cancer diagnosis



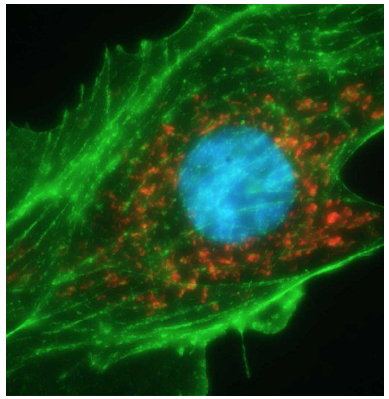
- No direct feedback during biopsy
- Labor-intensive
- Time-consuming

BrainAce: AI-based cancer diagnosis using endoscopy

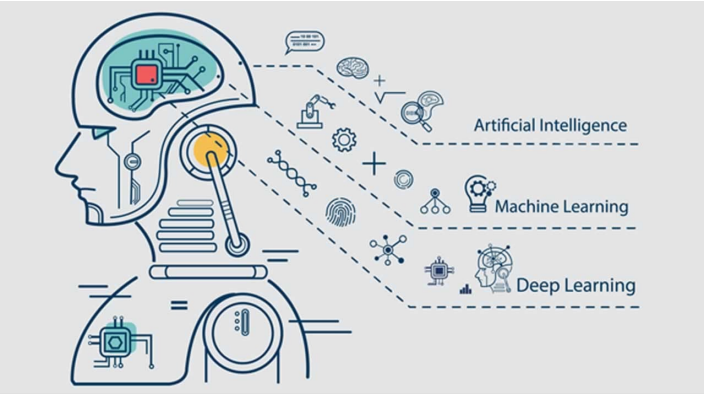


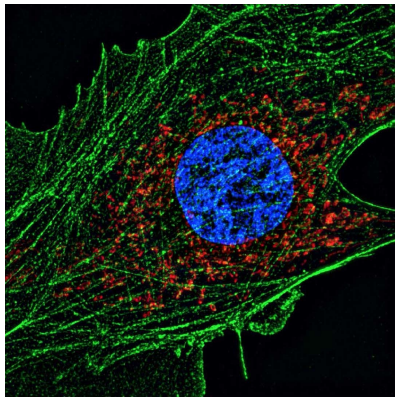
- Minimal invasiveness using ultra-thin fiber bundle
- Real-time imaging & diagnosis
- Deep learning-based reconstruction & classification

Smart Microscopy in biomedical applications



Credits: Zeiss





Credits: Zeiss

Background

Microscopy is one of the main diagnostic tools in biomedical applications. We employ adaptive optical elements in microscopy to enable fast and aberration free 3D-scans of zebrafish embryos. The adaptive elements are controlled by several applied voltages. The main challenge hereby is to control the behaviour of the adaptive elements, thus we use methods of machine learning for control, e.g. convolutional and deep neural networks or reinforcement learning.

Tasks

- Experimental characterization of adaptive optical components
- Evaluation of Machine Learning related control strategies
- Implementation and training of Neural Networks & agents
- Experiments with biological samples and biomedical background

python™

Contact

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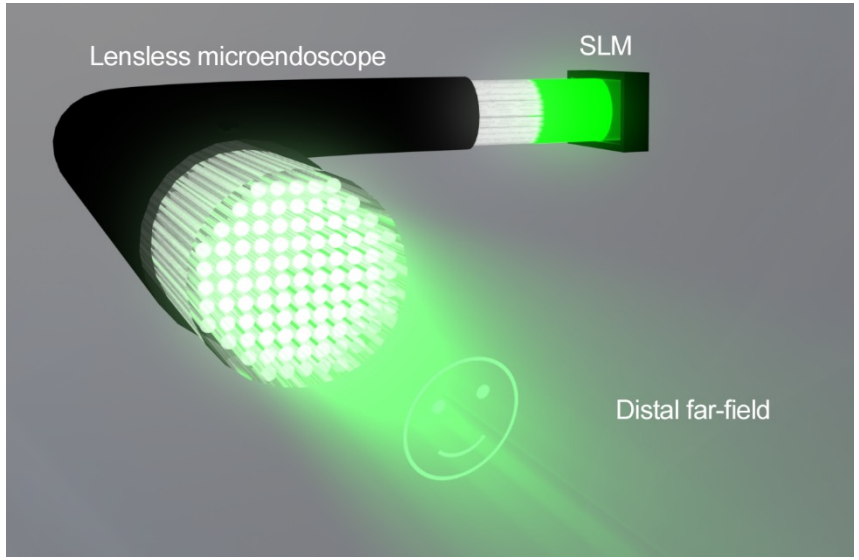
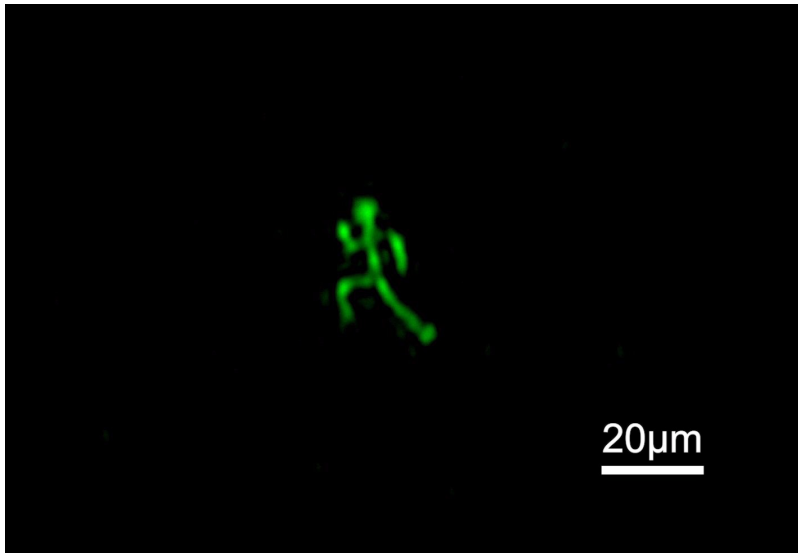
- Nektarios Koukourakis, BAR26, E-Mail: nektarios.koukourakis@tu-dresden.de
- Internet: http://tu-dresden.de/et/mst

Light field control through multicore fibers

- Real-time **holographic display** through multicore fiber
- **Video-rate** complex light field generation in far-field

Sun J. et al Scientific Reports 2022





Sun J. et al Scientific Reports 2022

Conclusion

Motivation: minimally invasive single shot 3D endoscope for in vivo diagnostics

Diffscope (Diffuser + CFB):

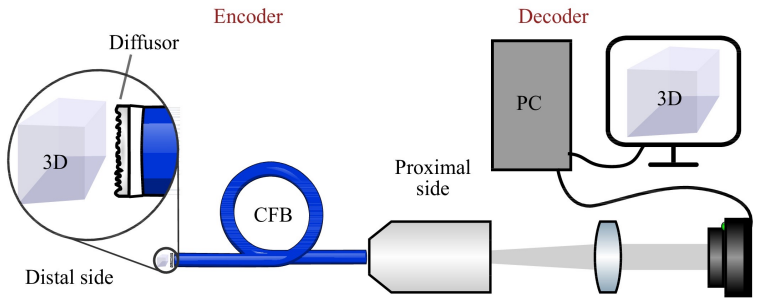
- 3D image encoded into 2D speckle pattern

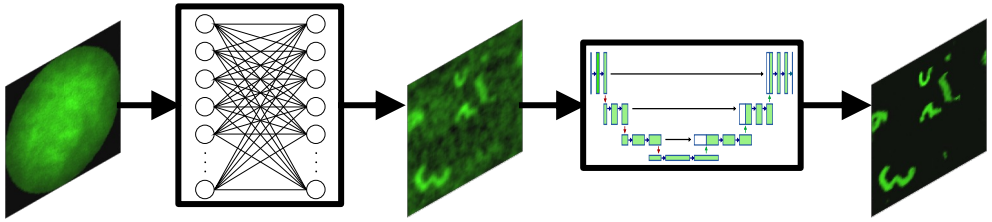
Neural Network Reconstruction (SLP + U-Net):

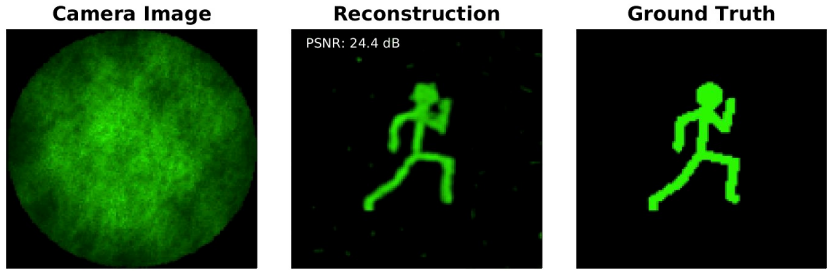
- enables video rate imaging with ~8 FPS
- Step-by-step reconstruction of CFB and diffuser decreases negative CFB influence

Outlook:

- Experimental validation of step-by-step reconstruction of CFB and diffuser
- Transfer to fluorescence imaging of tissue
- Structured Illumination







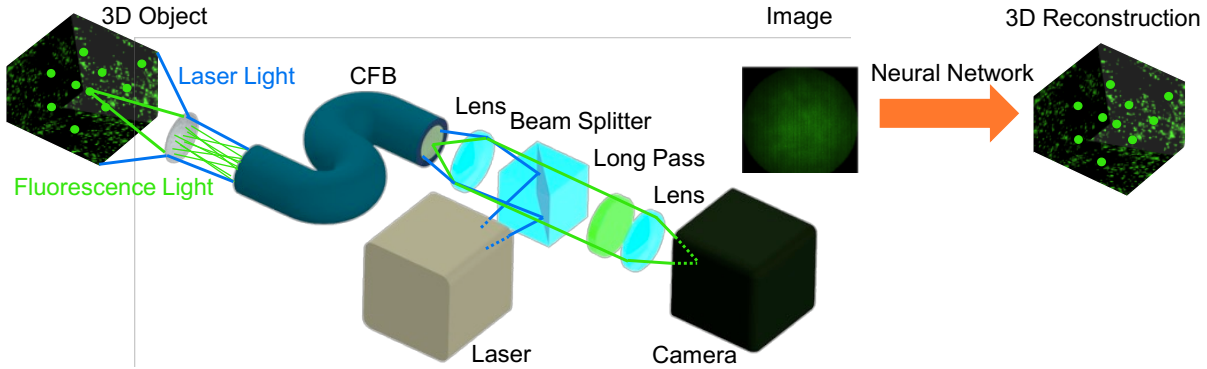
Physics-informed neural networks for 3D imaging with a diffuser endoscope

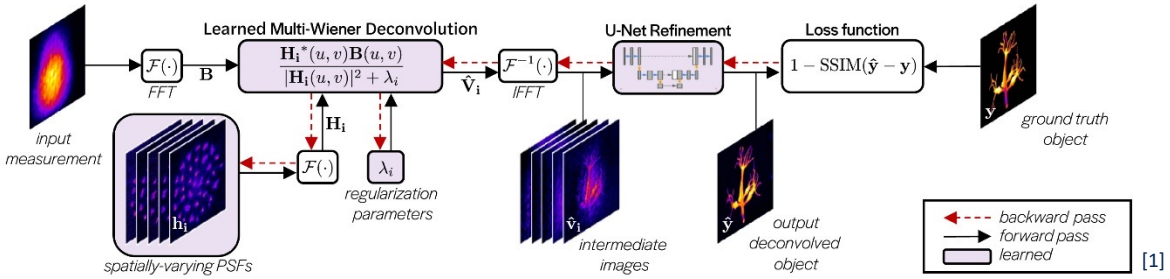
Motivation

Diffuser based imaging is a recent topic in computational optics. The diffuser generates a unique pseudorandom speckle pattern for every point within a volumetric field-of-view on an image plane. By solving the inverse problem, the 3D scene can be reconstructed computationally. In conjunction with imaging waveguides, this enables the realization of single shot 3D microendoscopes.

In order to increase the signal processing speed, neural networks can be used to reconstruct the 3D images from the 2D speckle patterns. Different architectures like the Single Layer Perceptron, U-Net or even cascaded neural networks have been employed for the reconstruction task.

A new physics-informed approach suggests using a trainable Wiener filter layer that is initialized by multiple point spread functions of the optical system to obtain multiple approximate reconstructions that are then improved by further layers resembling a U-Net structure.





[1]

Tasks

- Development of a Wiener filter based neural network for image reconstruction in Python

Key words

Endoscopy, Neural Network, Computational Imaging, Fiber Optics, Python

Contact

- Dipl.-Ing. Tom Glosemeyer, BAR 25, E-Mail: tom.glosemeyer@tu-dresden.de

[1] Kyrollos Yanny, Kristina Monakhova, Richard W. Shuai, and Laura Waller, "Deep learning for fast spatially varying deconvolution," Optica 9, 96-99 (2022)

High-Capacity Multiplexing in Multimode Optical Fibers

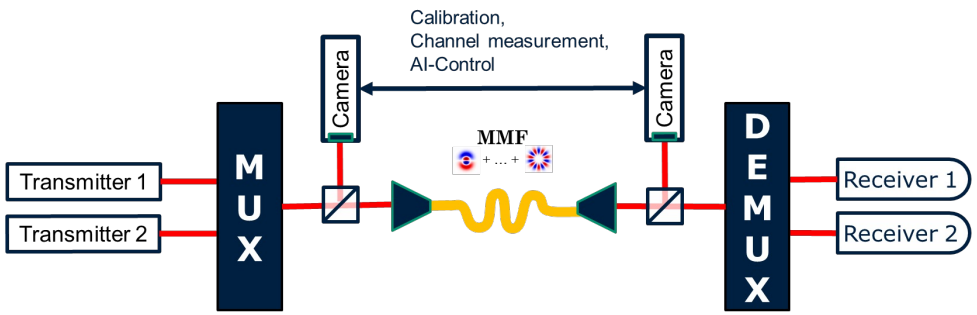
Motivation

Global internet communications backbone systems are mainly based on optical fibers. Whereas single mode fibers are used for long-haul, multimode fibers (MMFs) are well established for short-range distances. Further, MMFs offer high potential to increase data-capacity as well as data-security.

Due to distortions inside the MMF, compensation techniques are necessary to control data transport. For this, the distortions must be characterized. Here, the behavior on mode scrambling should be investigated. Therefore, tailored light fields need to be generated and the disturbed fields at the MMF output have to be measured.

After proper calibration, multiple parallel data-streams can be deployed within one single fiber. The goal is to evaluate boundary conditions in terms of capacity as well as parallel data-streams. One investigation could be how a change in the scrambling affects the calibration and further the capacity. For evaluation, both conventional and novel deep learning techniques are applicable.

The task allows to gain fundamental knowledge about fiber optical communications, optical setups, measurement techniques and AI-based approaches. Basic knowledge about optics and MATLAB/Python is desirable but not mandatory.



Tasks

- Build desired optical setup
- Beamforming and launching of MMF-suitable light fields
- Measurement of high-capacity data streams
- Evaluation within (mode-dependent) transmission matrix

Keywords

fiber communication, beamforming, light field measurement, digital holography, signal processing, MATLAB

Contact

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Website: http://tu-dresden.de/et/mst

Studien- / Diplomarbeit / SHK / WHK

Advanced Beamshaping mittels physikgestützter KI

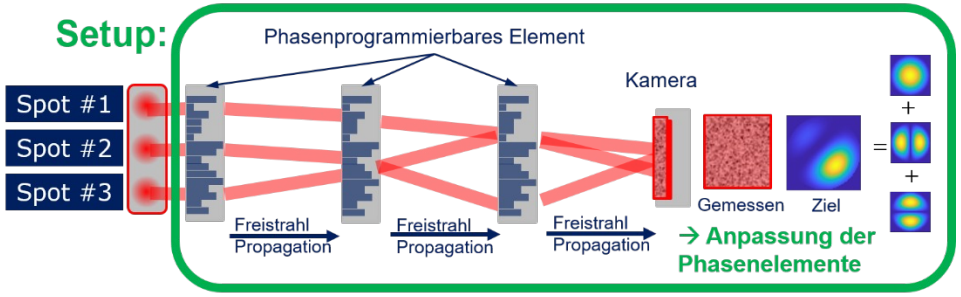
Motivation

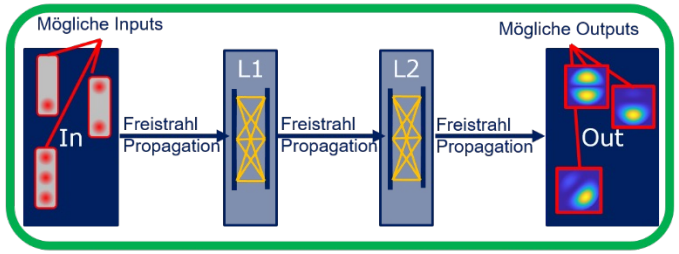
Für die globale Datenübertragung stellen optische Wellenleiter ein wichtiges Schlüsselelement des Internets dar. Durch räumliches Multiplex bieten mehrmodige Glasfaserm (MMF) das Potential für hochperformante und sichere Übertragungsnetzwerke. Dafür ist es notwendig, Daten über die unabhängigen räumlich parallelen Kanäle der MMF optisch zu übertragen.

Ein neuartiger Ansatz besteht darin, mittels phasenprogrammierbarer Optiken und Freistrahlpropagation die Einkopplung in die MMF zu ermöglichen. Die dafür eingesetzten Phasenmasken werden über einen Optimierungsalgorithmus gefunden. Durch die hohe Anzahl paralleler Kanäle erfordert die Justage der Phasenmasken einen hohen Aufwand. Weiterhin können systembedingte Abweichungen und Unsicherheiten nur schwer durch den Optimierungsalgorithmus berücksichtigt werden.

Um dieses Problem zu minimieren, soll in dieser Arbeit der Optimierungsalgorithmus durch ein KI Modell ersetzt werden. Dabei wird zunächst das Verhalten des optischen Systems erfasst und ein digitaler Zwilling erzeugt. Dieser kann anschließend für die Berechnung geeigneter optischer Phasenmasken zur Implementierung des räumlichen Multiplex verwendet werden. Das erzeugte Modell soll anschließend mit der konventionellen Optimierungsmethode verglichen werden und hinsichtlich Demultiplex untersucht werden.

Setup:





Physikgestütztes KI Modell

Aufgaben

- Implementierung des KI Modell als digitaler Zwilling des Experiments
- Vergleich mit numerischem Algorithmus
- Untersuchung der Modulationsgüte und Adaption auf Demodulation

Keywords

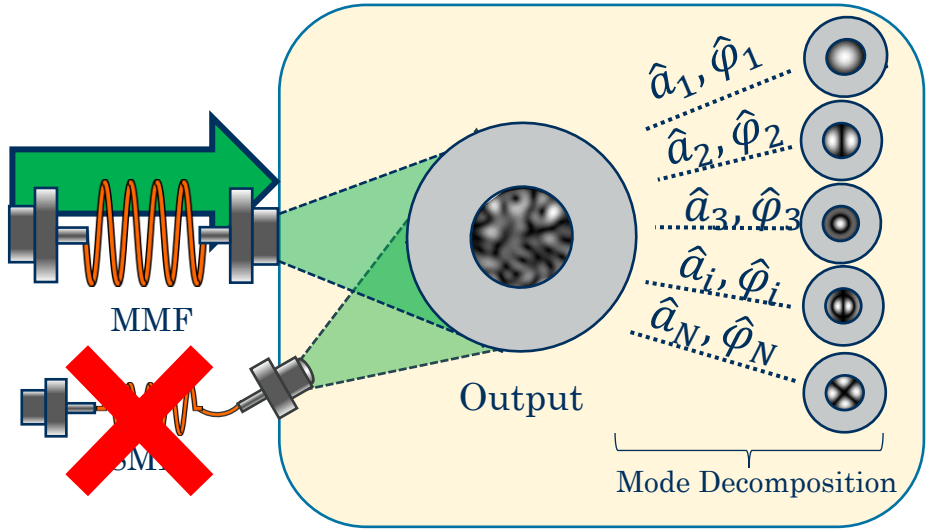
Künstliche Intelligenz, Maschinelles Lernen, Strahlformung, Faserkommunikation, MATLAB, Python/TensorFlow

Kontakt

Dipl.-Ing. Dennis Pohle, BAR 24, E-Mail: dennis.pohle@tu-dresden.de

Motivation

TM Measurement: what is required? **--- mode decomposition**



- Phase and amplitude measurement of MMF-Output
- If possible: referenceless

Currently:

Digital Holography

+ Quality
- Reference beam
- Impractical for application

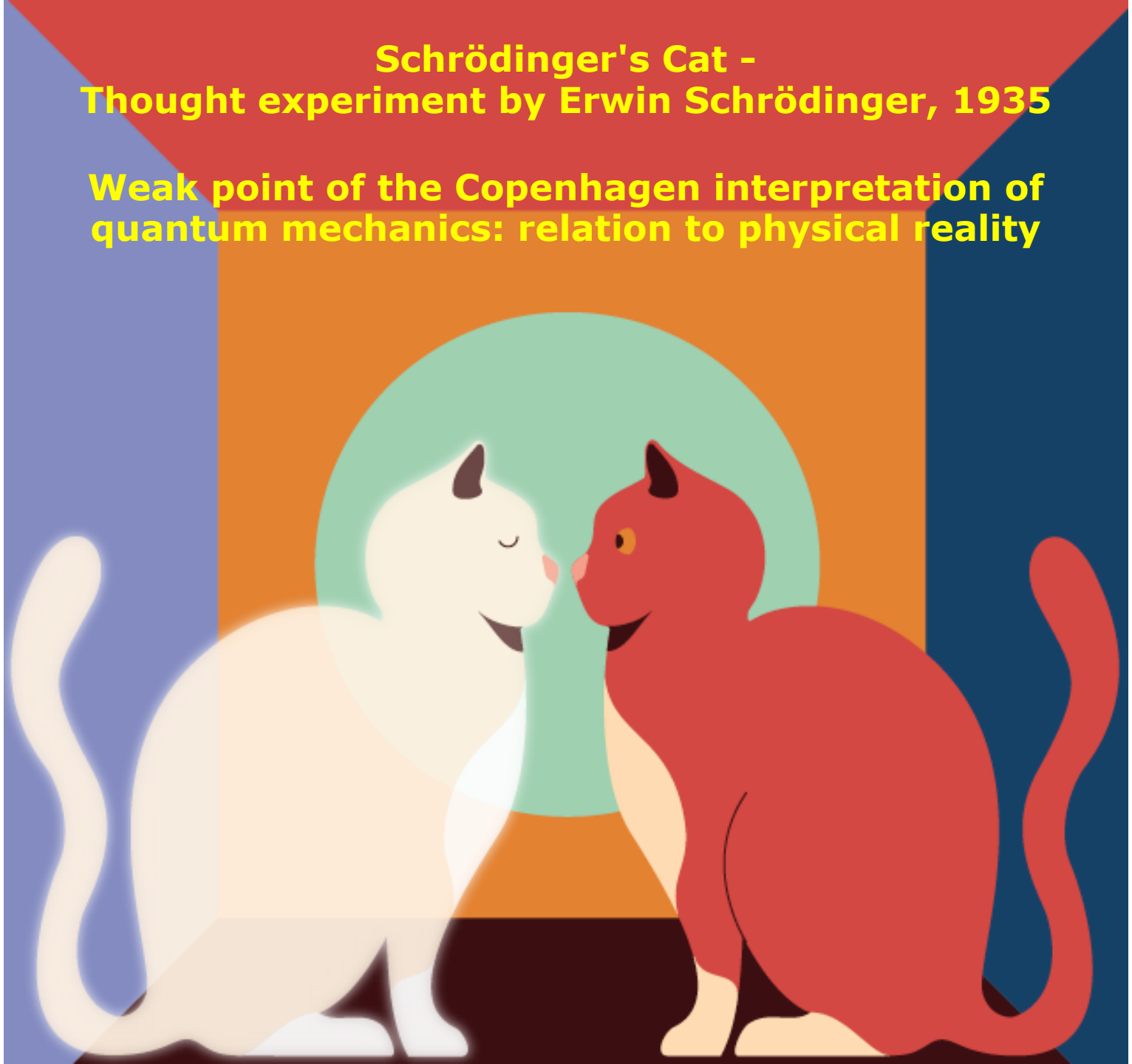
Qian Zhang
(during an award cerenomy)

Approach: Deep Neural Network (DNN)

- Training a DNN with synthetic data – offline
- Measurement with amplitudes from camera pictures

→ reconstruct amplitude <u>and phase</u>

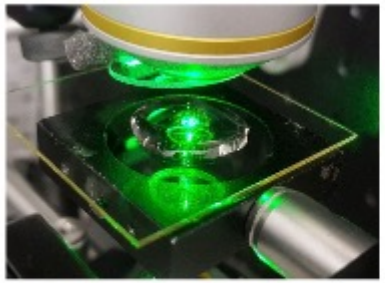
+ Referenceless
+ Intensity-only images



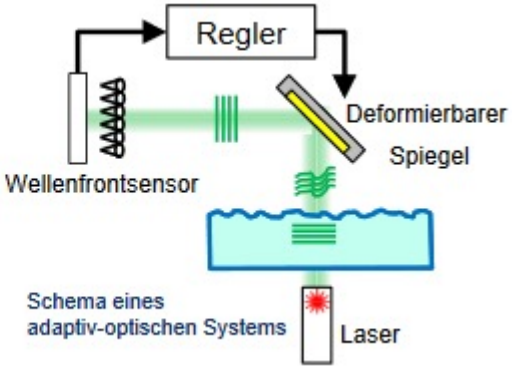
Quellen: acatech (Hrsg.): Quantentechnologien (acatech HORIZONTE), München 2020
& Kagermann, H., Süssenguth, F., Körner, J., Liepold, A. (2020): Innovationspotenziale der Quantentechnologien der zweiten Generation (acatech IMPULS), München.

Abschlussarbeiten: Some exmples

Wellenfrontschätzung in der adaptiven Optik

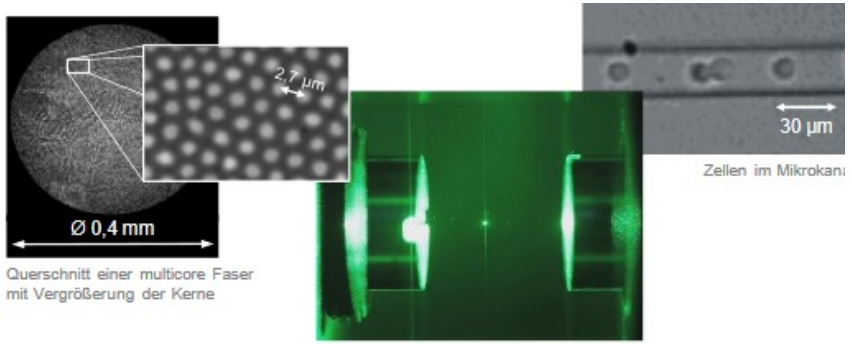


Anwendungsfall: Optische Messungen Durch eine sich bewegende Tropfen-oberfläche



Schema eines adaptiv-optischen Systems

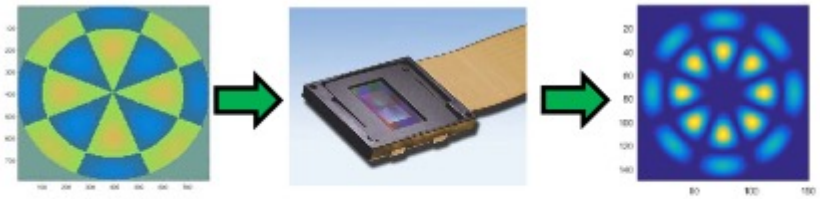
Optische Pinzette zur Rotation von Zellen in einem Mikrokanal



Querschnitt einer multicore Faser mit Vergrößerung der Kerne

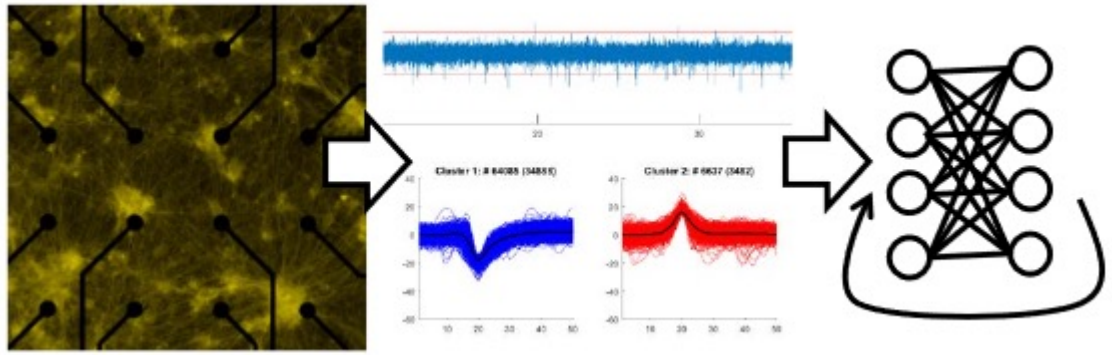
Zellen im Mikrokan

Optische Wellenfrontformung für die sichere Informationsübertragung



Erzeugung einer Modenfeldverteilung mit einem SLM (links: Eine ermittelte Pixelverteilung zur Anzeige auf dem SLM. Mitte: SLM. Rechts: Entstehende Lichtfeldverteilung.)

Analyse organischer neuronaler Netze mit künstlichen neuronalen Netzen



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Vertiefung – Pflicht (6/4/0)
- 5. Semester: Messtechnik II: Mess- und Sensortechnik (2/1/0)
- 5. Semester: Digitale Holographie und Bildverarbeitung (1/1/0)
- 6. Semester: Messtechnik III: Messsystemtechnik (1/1/0)
- 6. Semester: Lasermesstechnik (2/1/0)

Vertiefung – Wahlpflicht (2 SWS):
- 5. Semester: Biomedizinische Systemtechnik und Optogenetik (1/0/0)
- 5. Semester: Lasermesssysteme für die Fluidtechnik (2/0/0)
- 5. Semester: Projekt Photonische Messsystemtechnik (0/1/0)
- 5./6. Semester: Oberseminar Messsystemtechnik (0/2/0)
- 6. Semester: Mechatronische Lasersensoren (2/0/0)
- 6. Semester: Praktikum Lasersensorik (0/0/1)