

Bachelorarbeit

Winkelmessung durch magnetische Sensor-Arrays und Toleranzkompensation mittels Gauß-Prozess

Fakultät Technik und Informatik
Department Informations- und Elektrotechnik

Faculty of Computer Science and Engineering Department of Information and Electrical Engineering

Übersicht



- Applikation
- Kennfelder
- Datenadaption
- Gauß-Prozesse

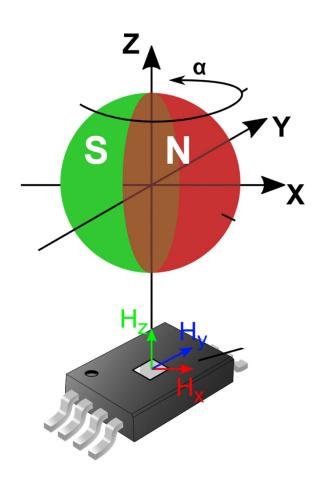
Übersicht



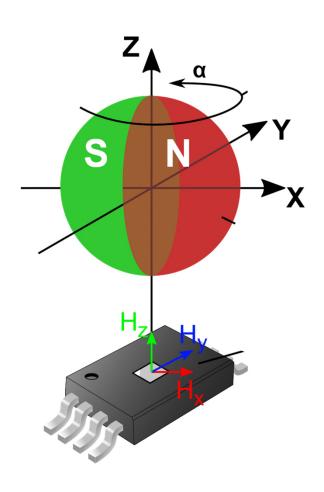
- Applikation
- Kennfelder
- Datenadaption
- Gauß-Prozesse

- Software-Aufbau
- Simulation Sensor-Array
- Simulation Gauß-Prozesse
- Erprobungsexperimente
- Zusammenfassung



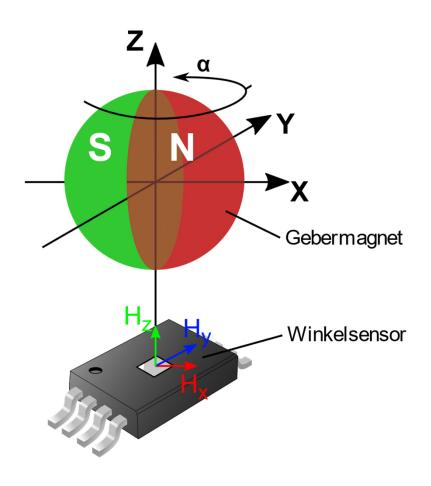






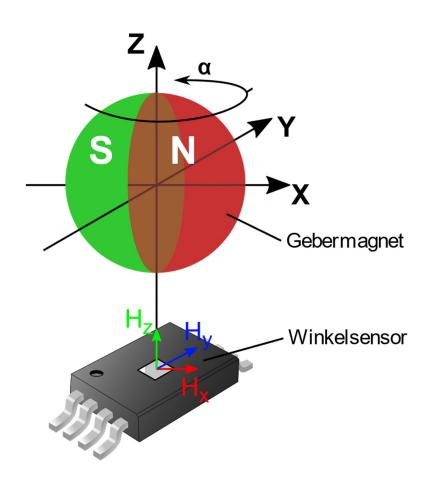
Kontaktlose Winkelmessung





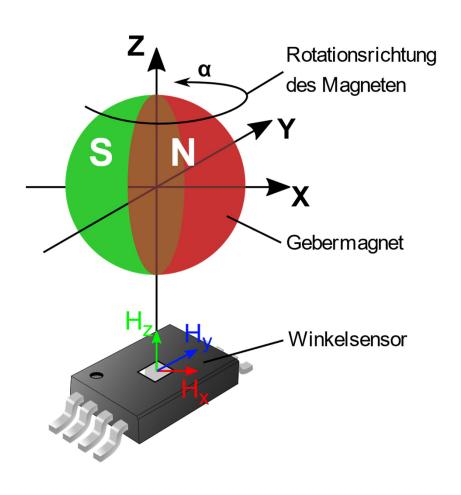
- Kontaktlose Winkelmessung
- Winkel encodiert durch Magnetfeld

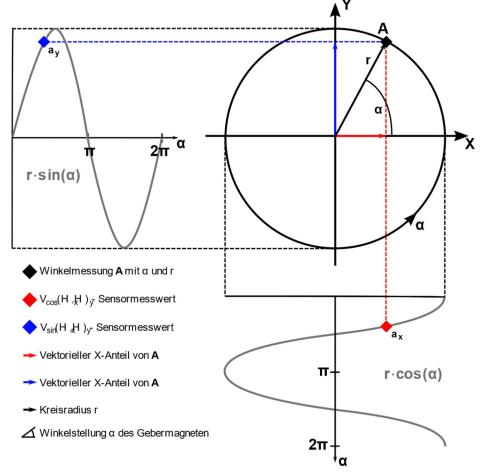




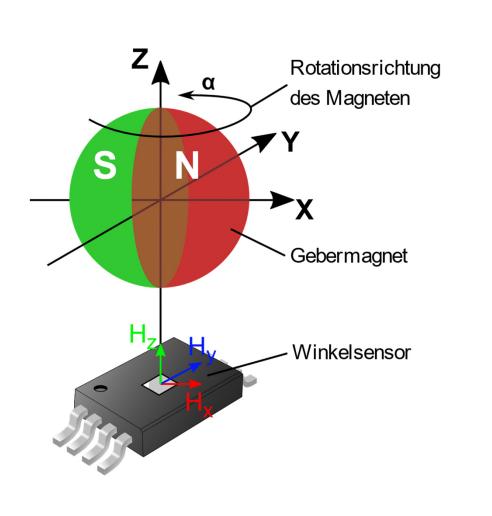
- Kontaktlose Winkelmessung
- Winkel encodiert durch Magnetfeld
- Feldstärkenmessung in X-/ Y-Richtung

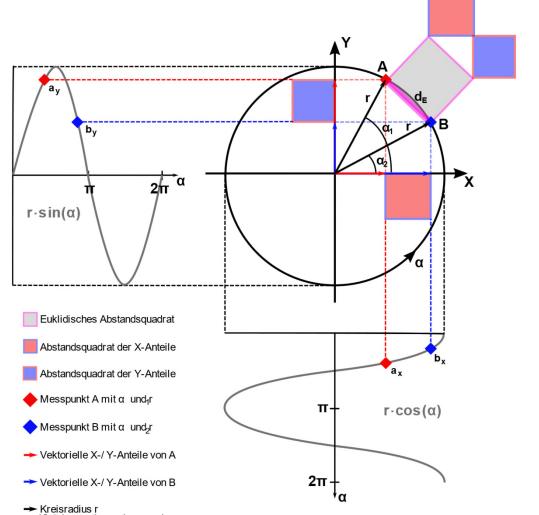




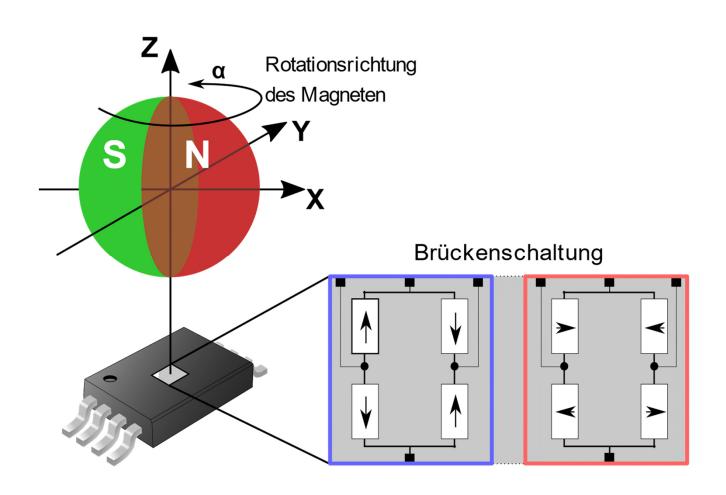




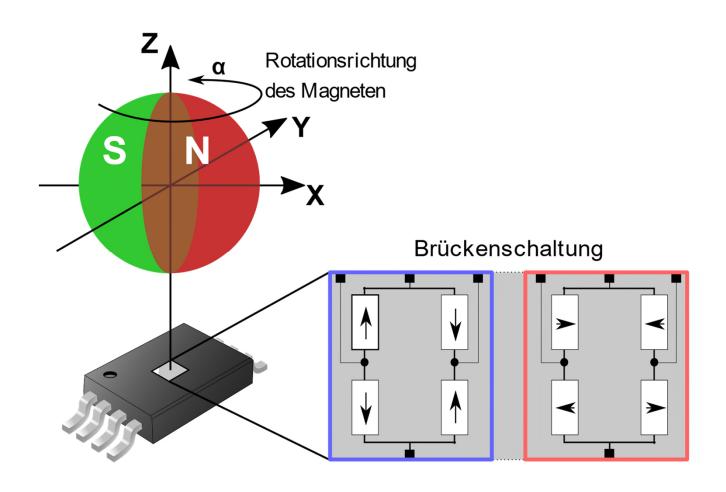






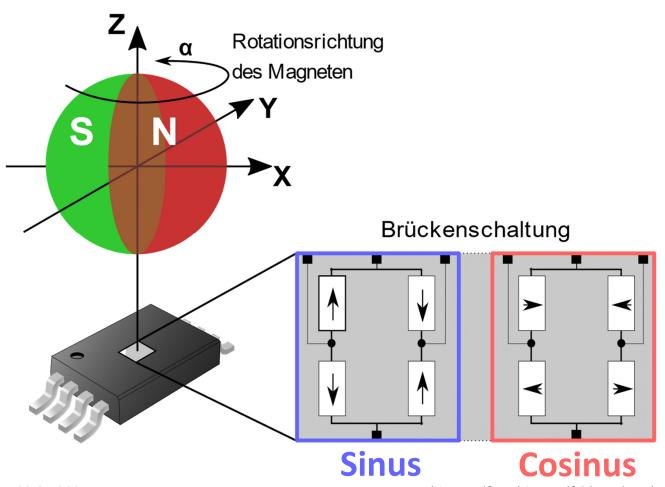






• TMR-Sensor

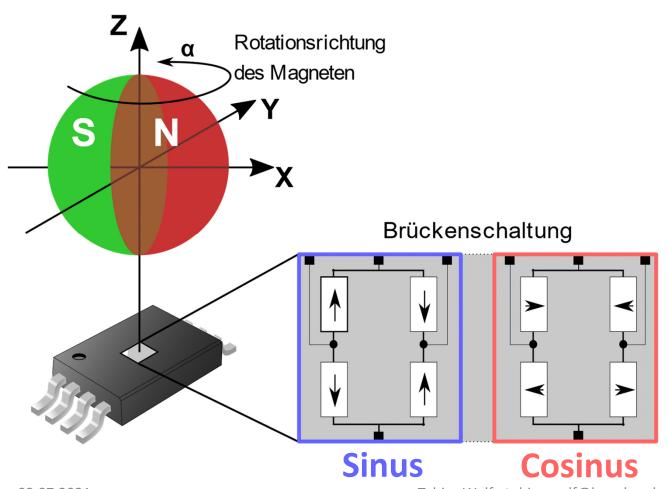




- TMR-Sensor
- Wheatstone'sche

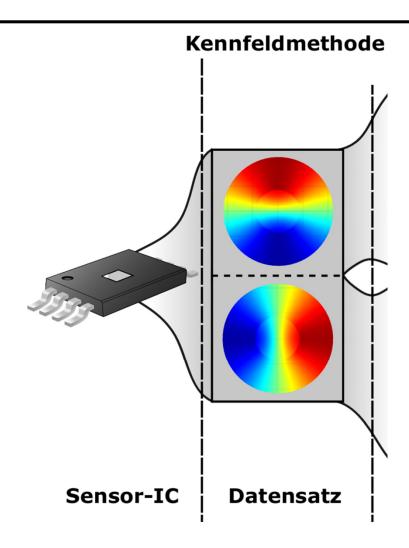
Messbrücken



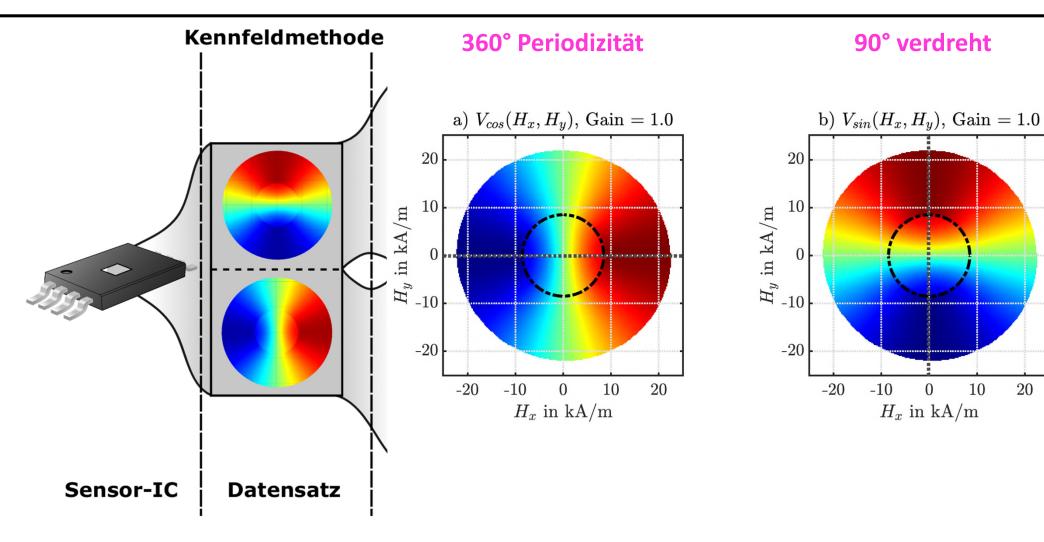


- TMR-Sensor
- Wheatstone'scheMessbrücken
- 90° verdreht zueinander
- 360° Periodizität









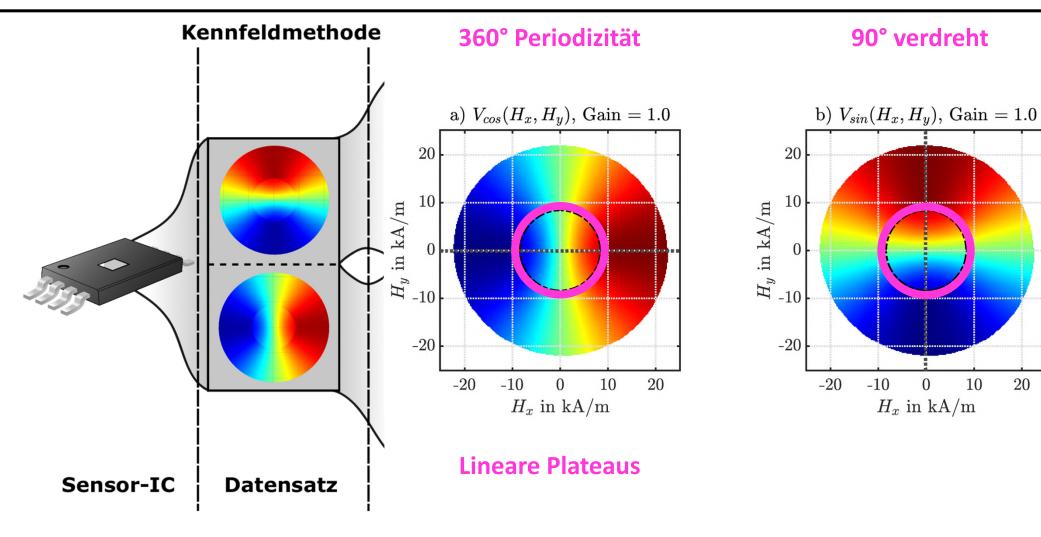
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-100

-150

20



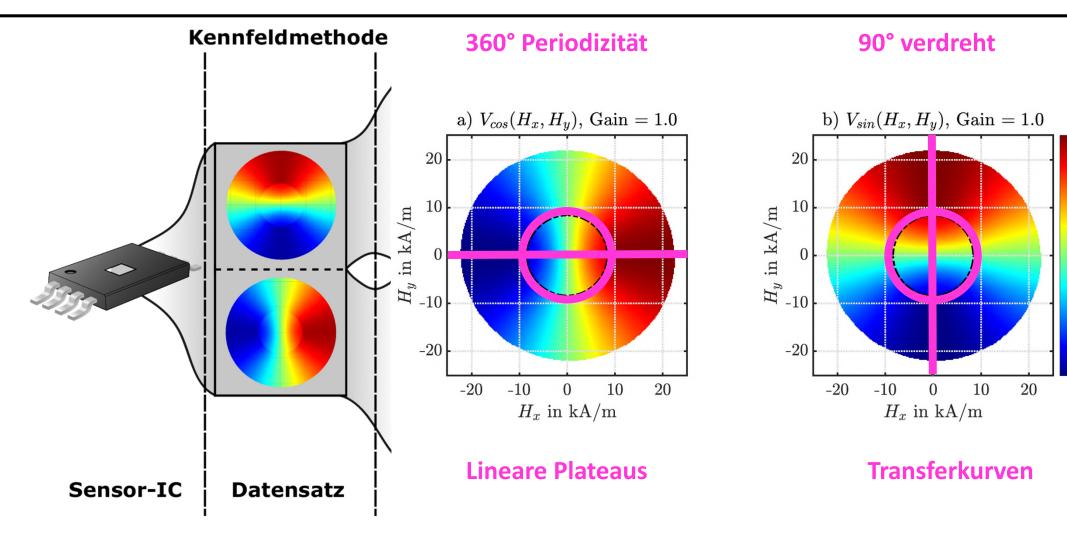


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-100

-150



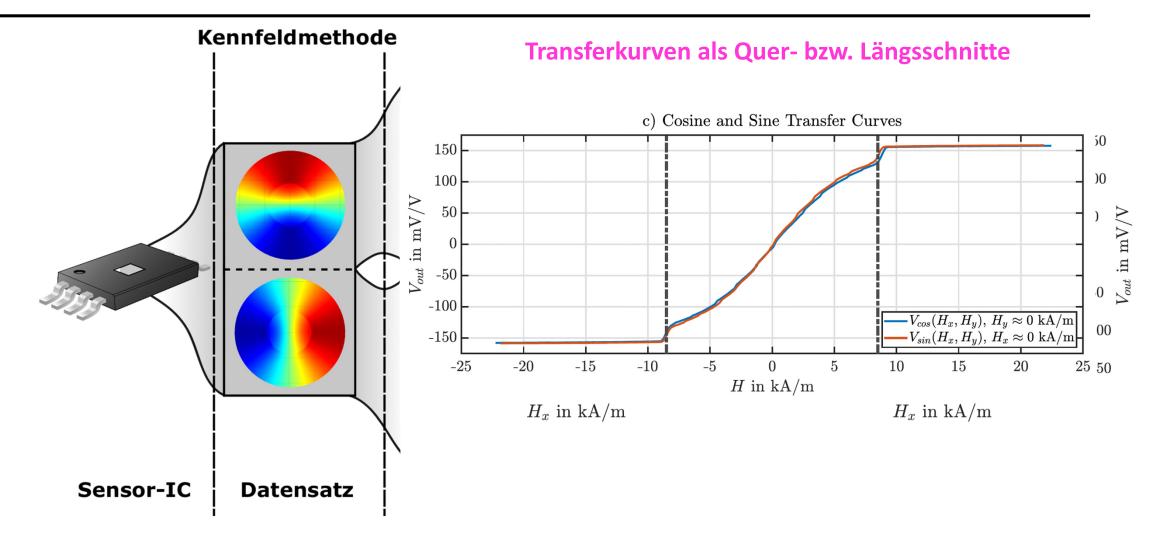


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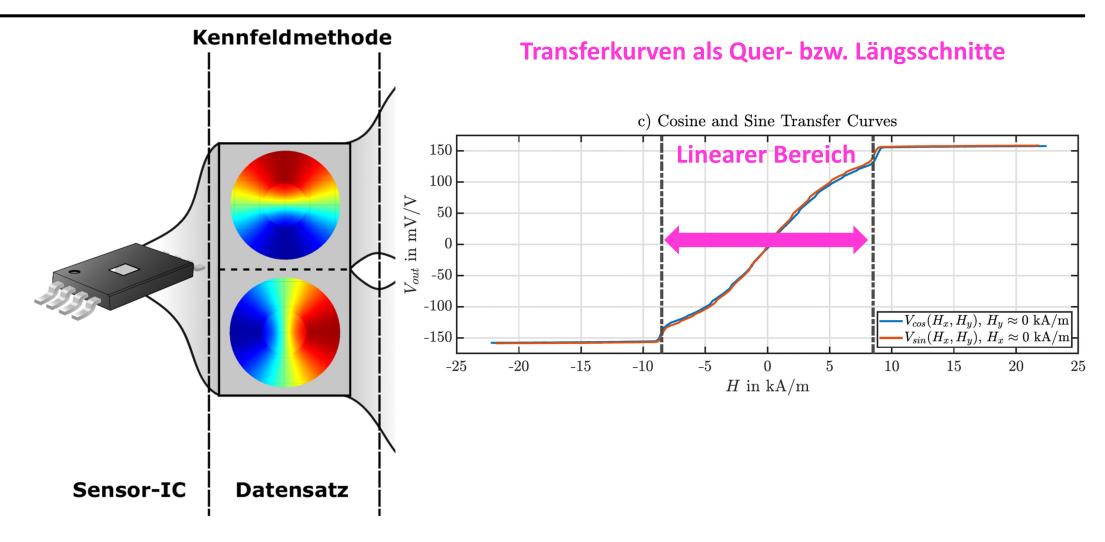
-100

-150

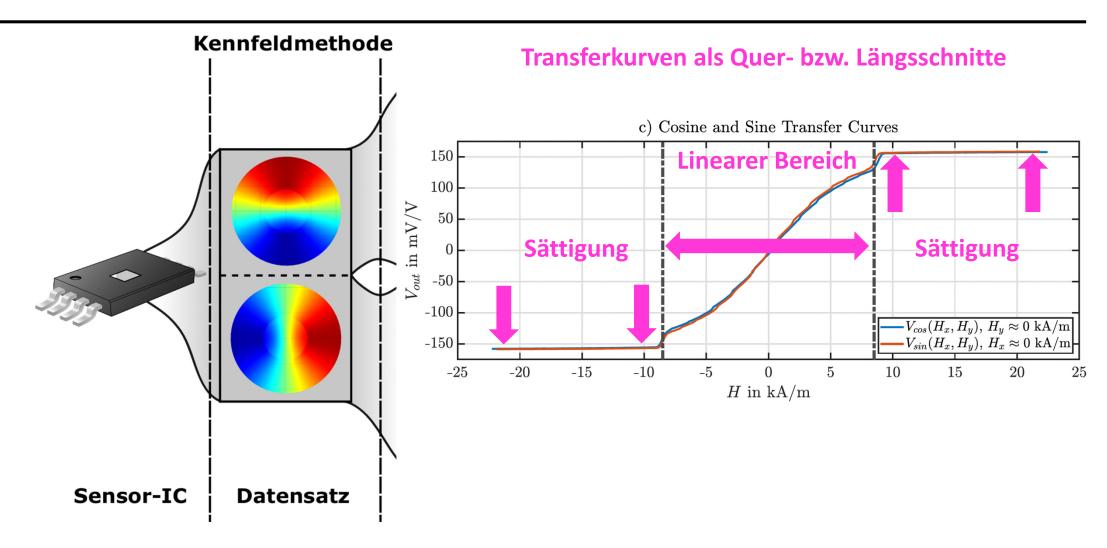




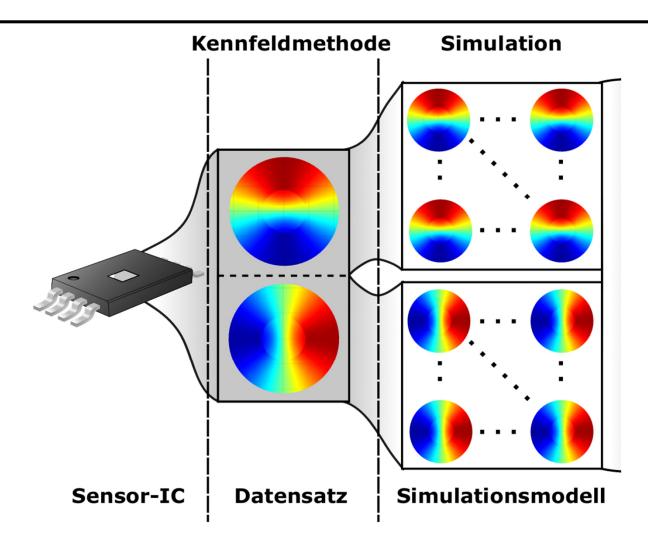




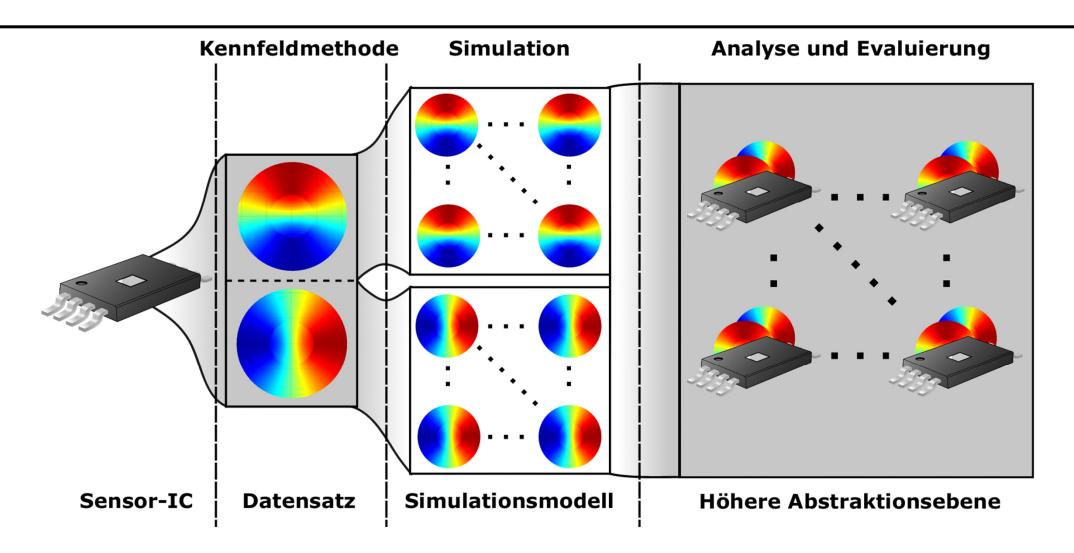




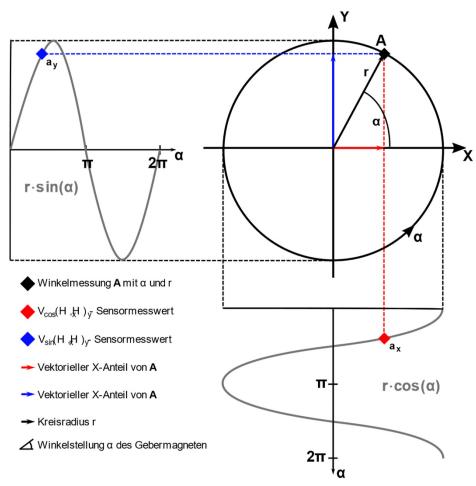




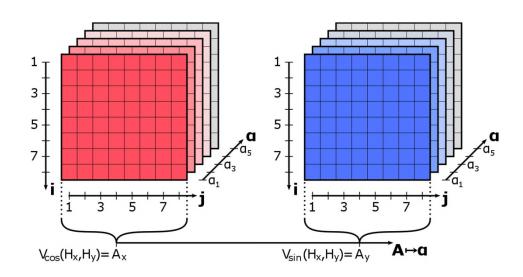


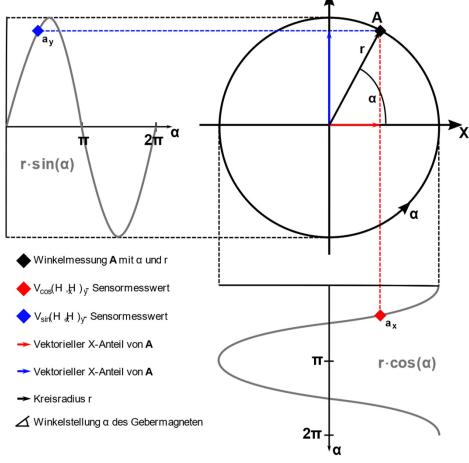




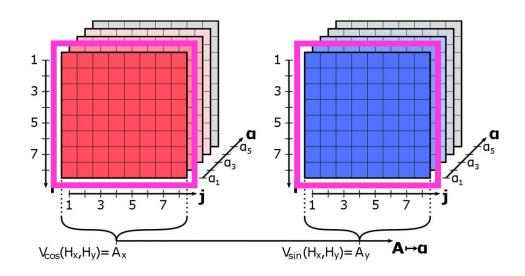


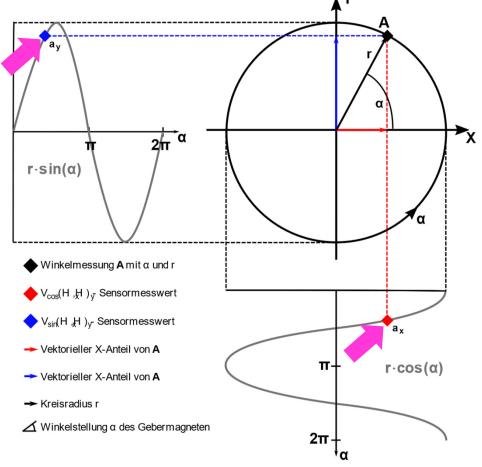




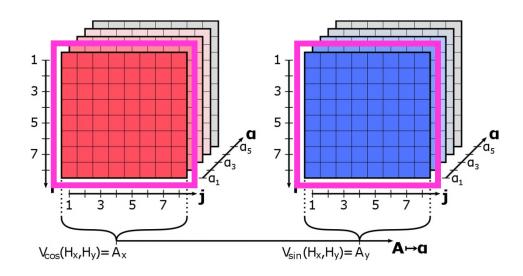




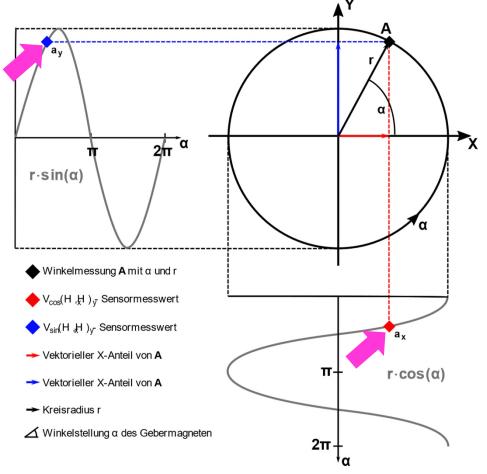




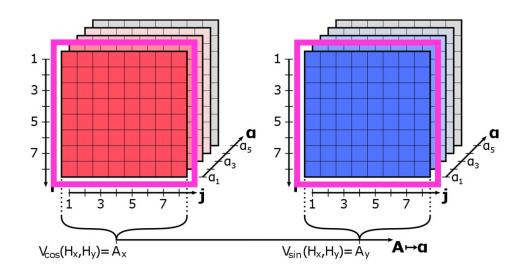




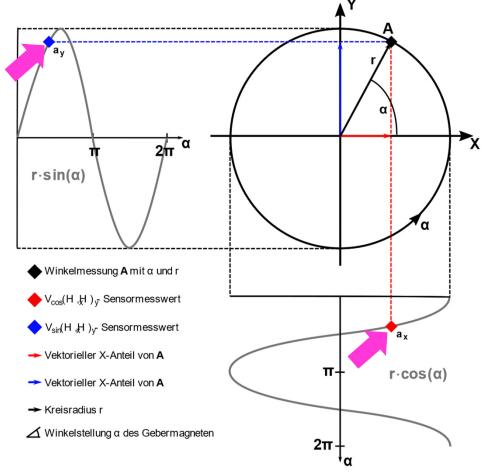
Arrays als lange Vektoren



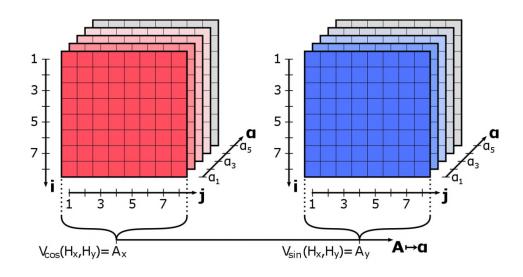




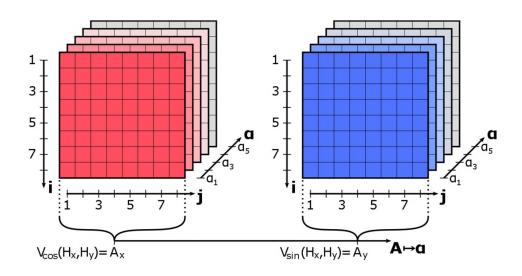
- Arrays als lange Vektoren
- Frobenius-Norm





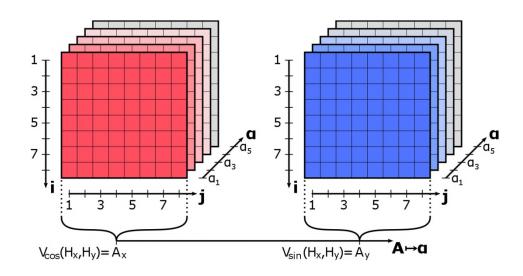






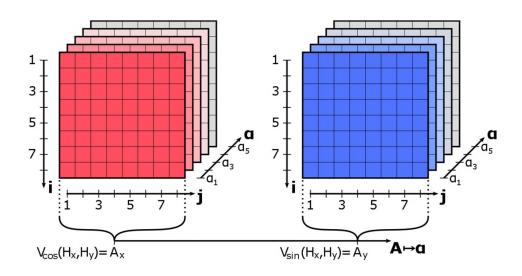
Lernen über Trainingsdaten





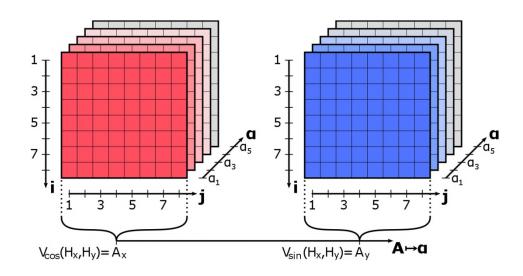
- Lernen über Trainingsdaten
- Anpassung über Testdaten
- Optimieren über Parameter





- Lernen über Trainingsdaten
- Anpassung über Testdaten
- Optimieren über Parameter
- Vorhersage durch Stützwerte

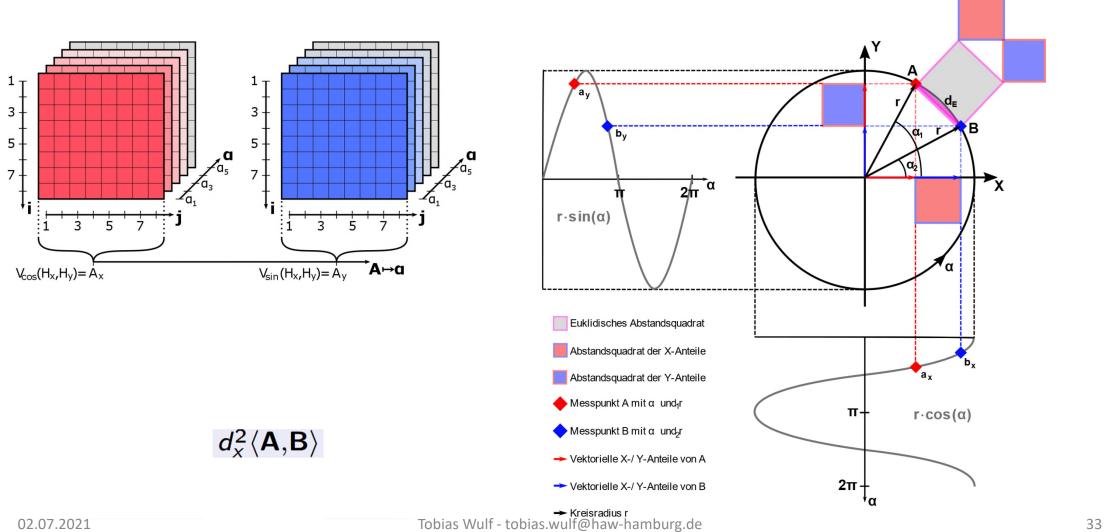




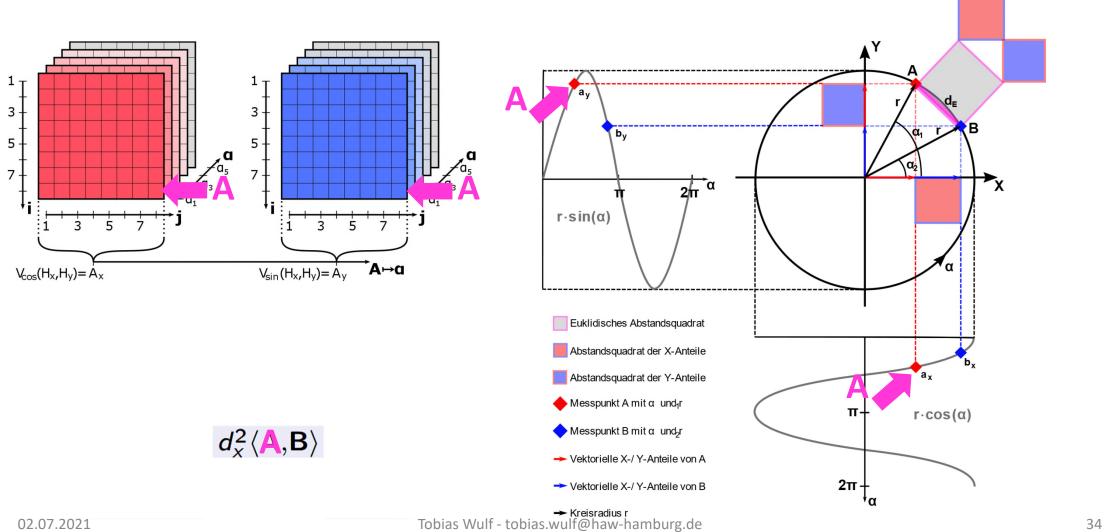
- Lernen über Trainingsdaten
- Anpassung über Testdaten
- Optimieren über Parameter
- Vorhersage durch Stützwerte

Kovarianzfunktion (Kernel) ist Verhaltensmaßgebend!

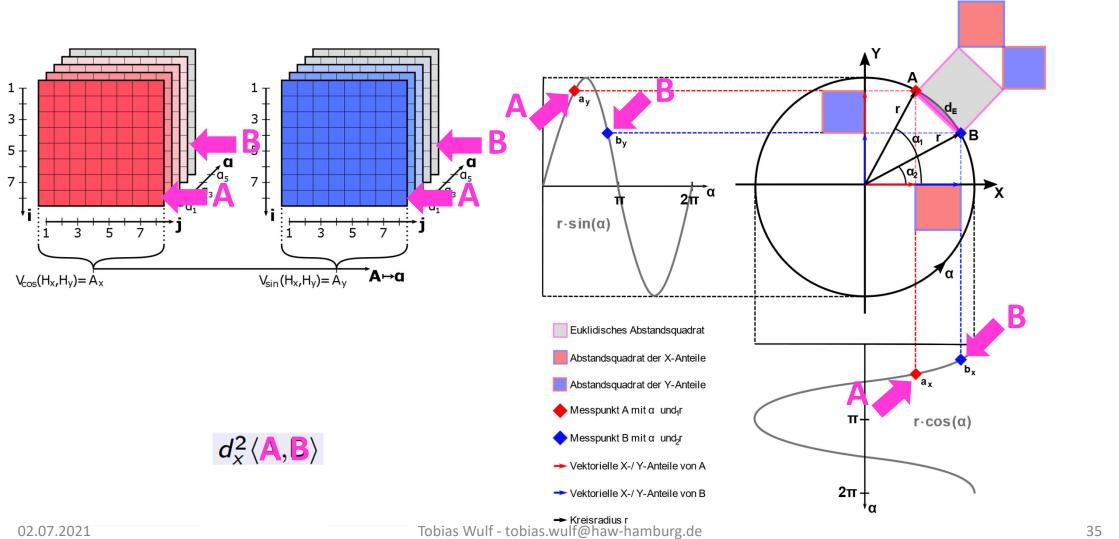




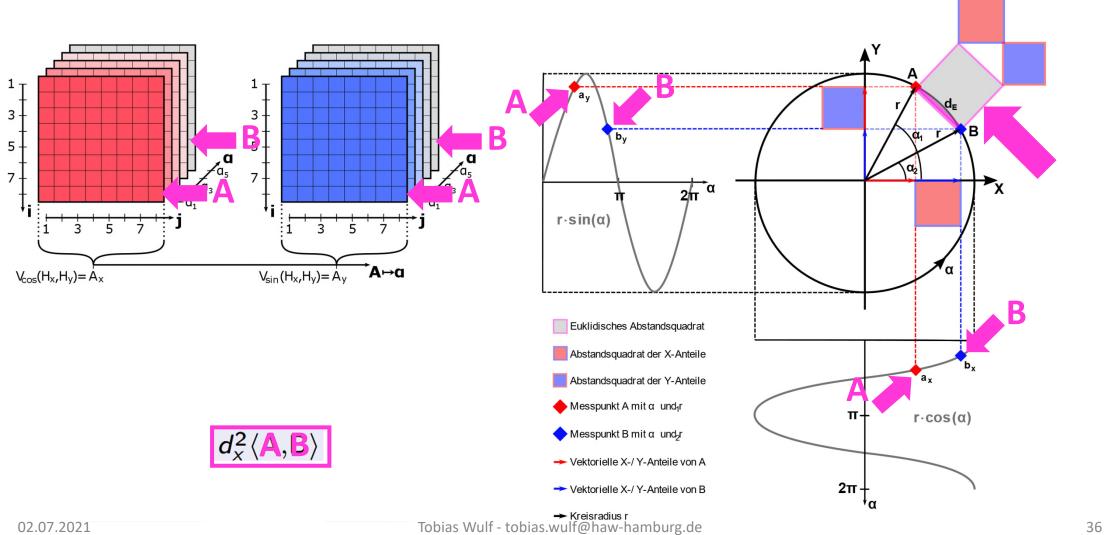




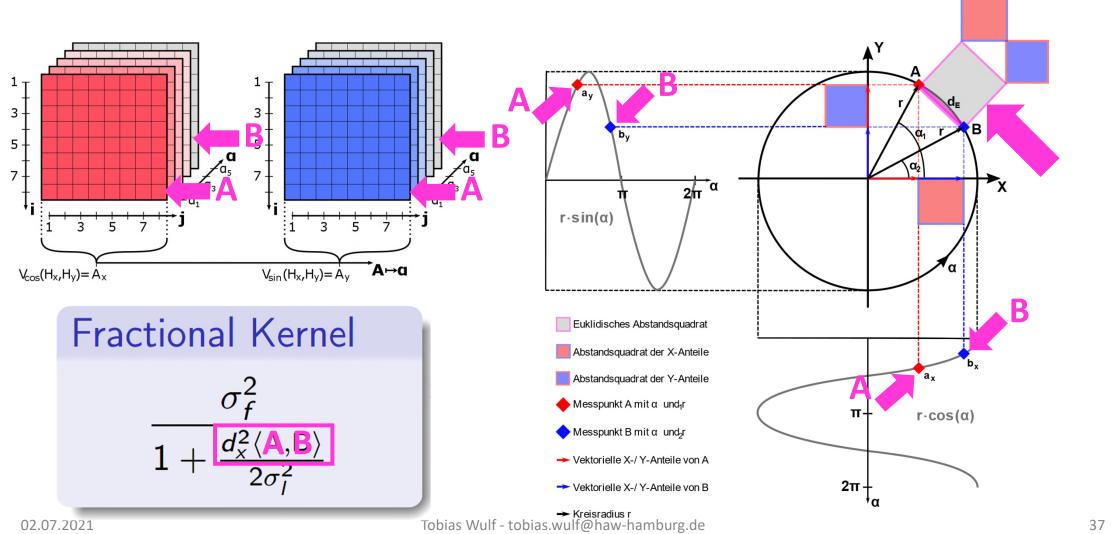




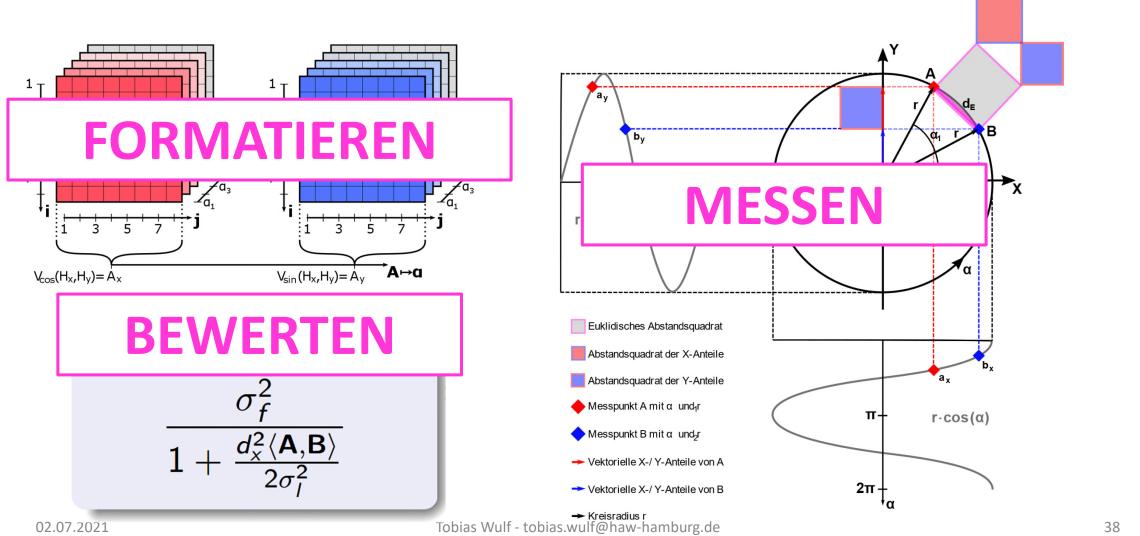




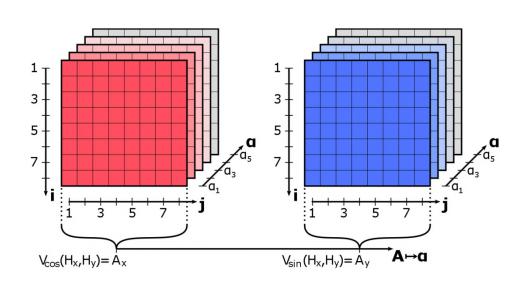


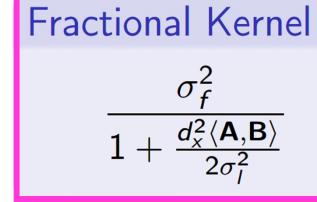


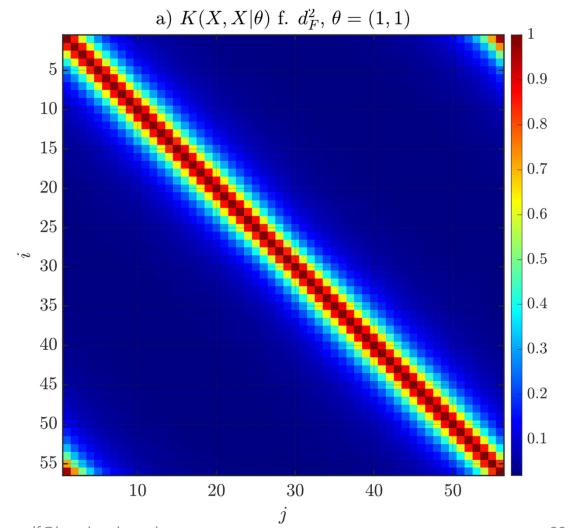




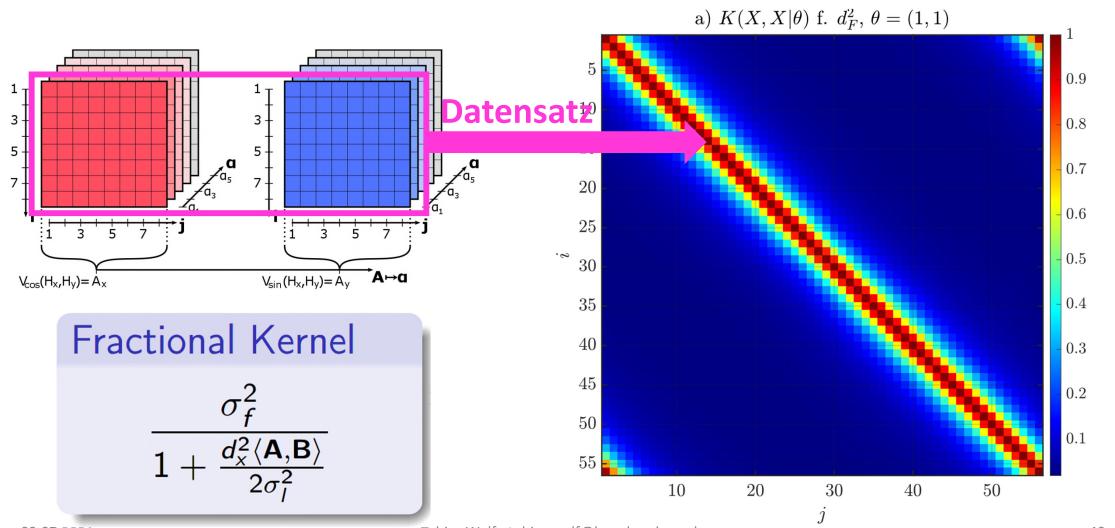




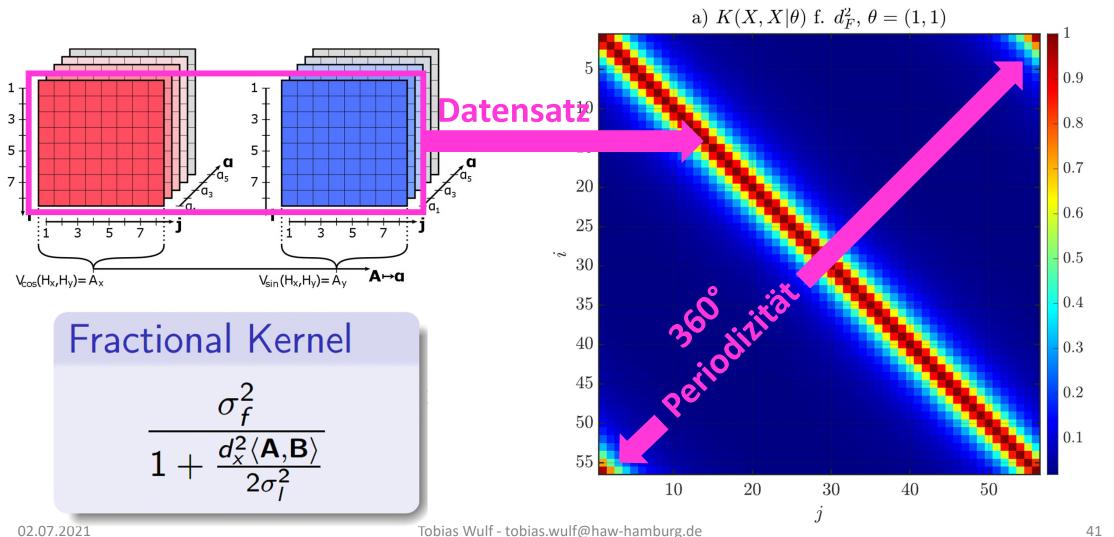








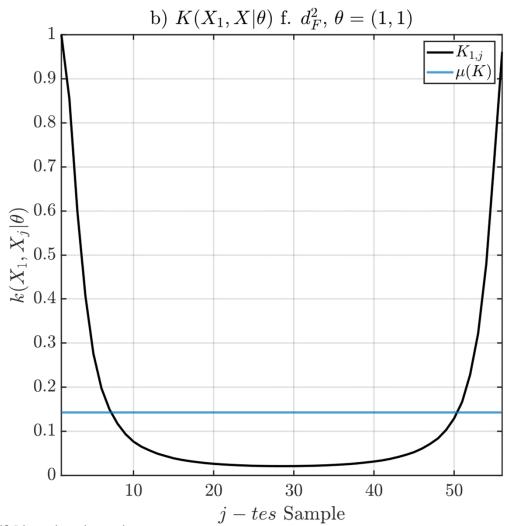




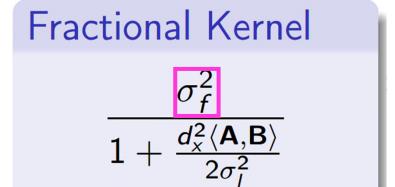


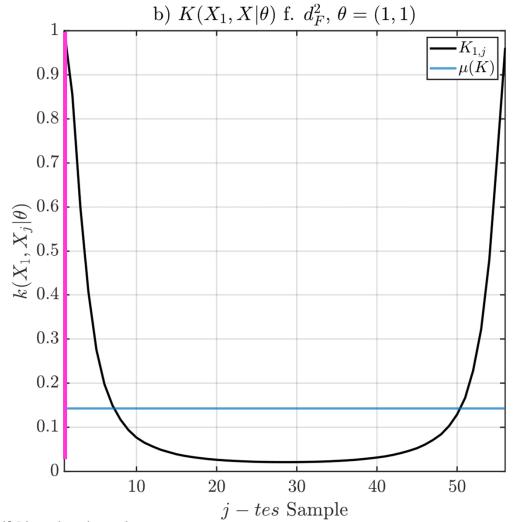
Fractional Kernel

$$rac{\sigma_f^2}{1+rac{d_{_{\!X}}^2\langle\mathbf{A},\mathbf{B}
angle}{2\sigma_I^2}}$$

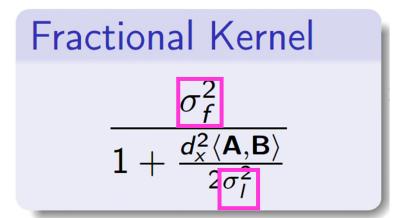


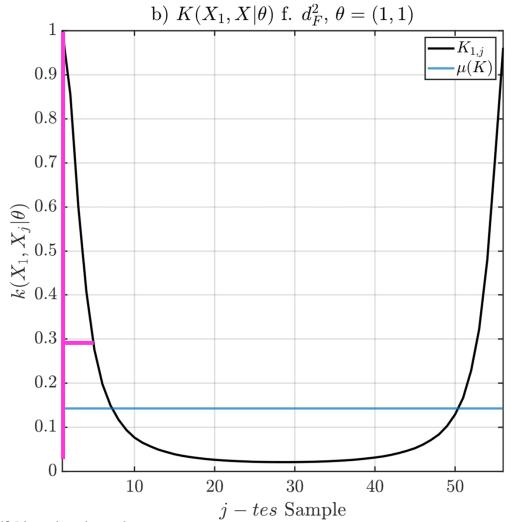




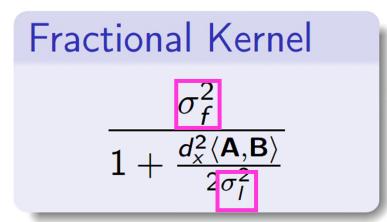


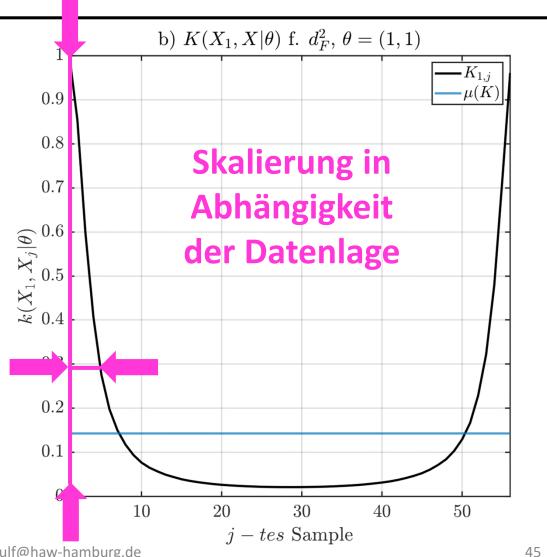






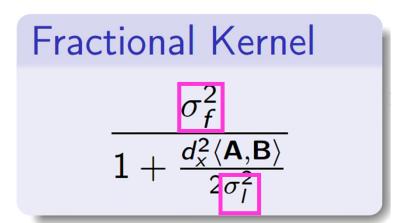


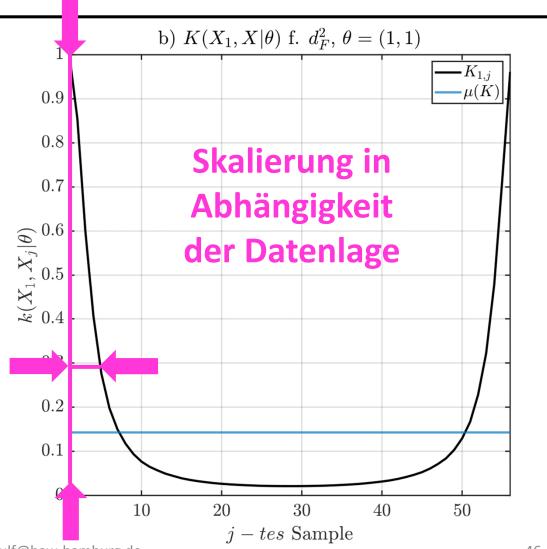






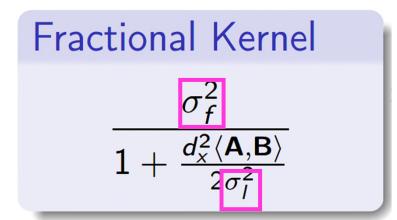
Kontrolle über Einflussnahme

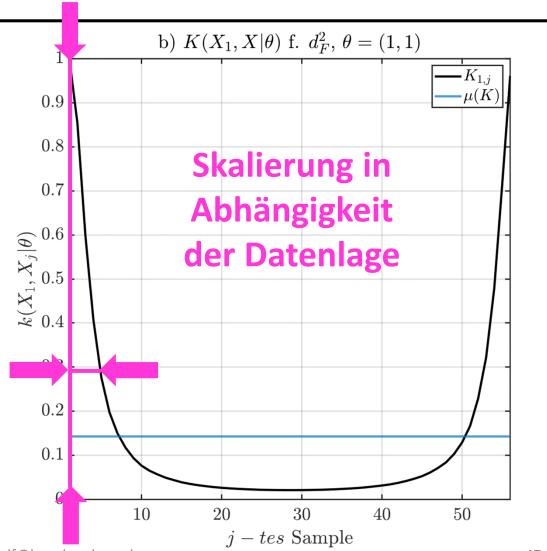






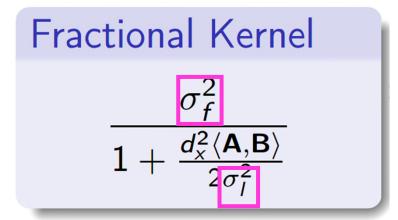
- Kontrolle über Einflussnahme
- Datenfit über Plausibilitäten

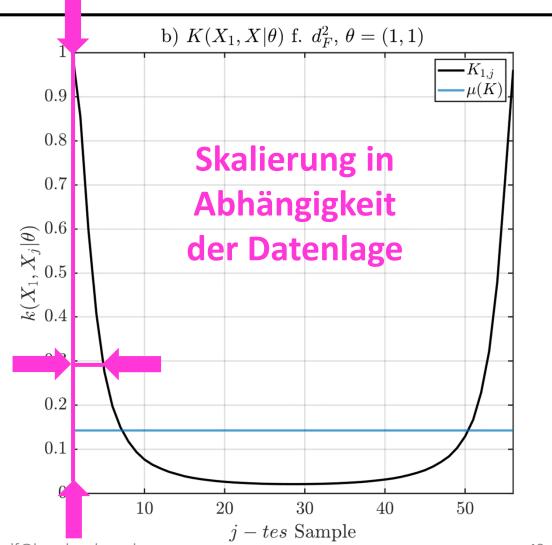






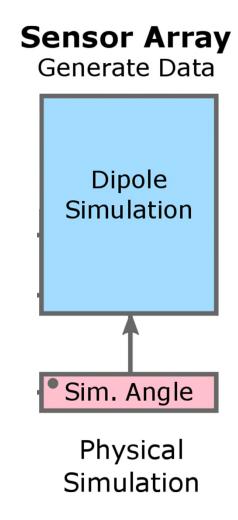
- Kontrolle über Einflussnahme
- Datenfit über Plausibilitäten
- Modellgeneralisierung über Verluste















Analyze Data

Gaussian Process Regression

Pred. Angle

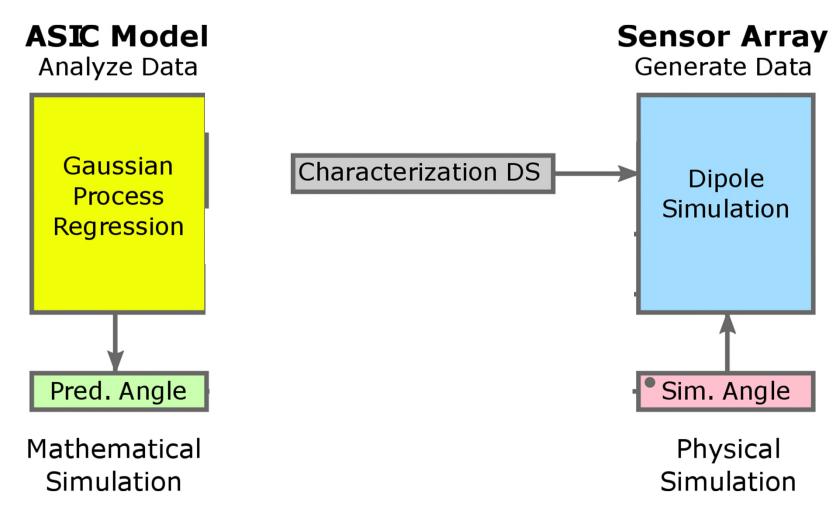
Mathematical Simulation

Sensor Array Generate Data

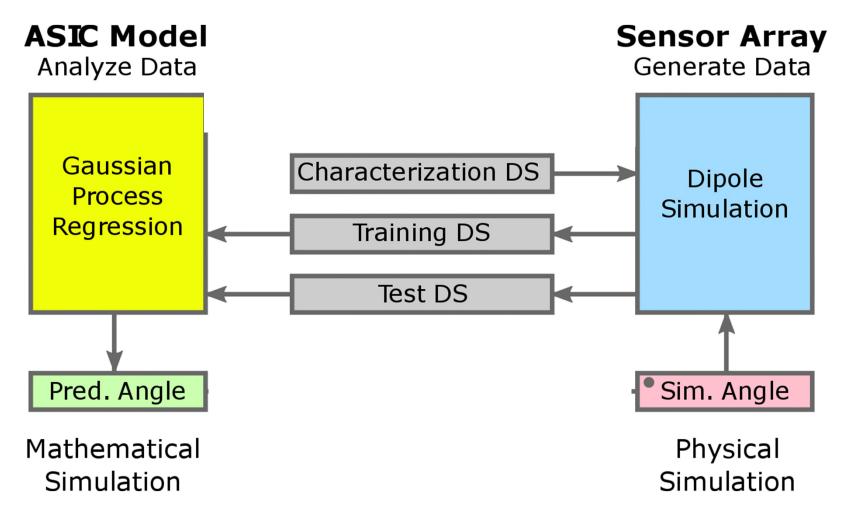
Dipole Simulation Sim. Angle

Physical Simulation

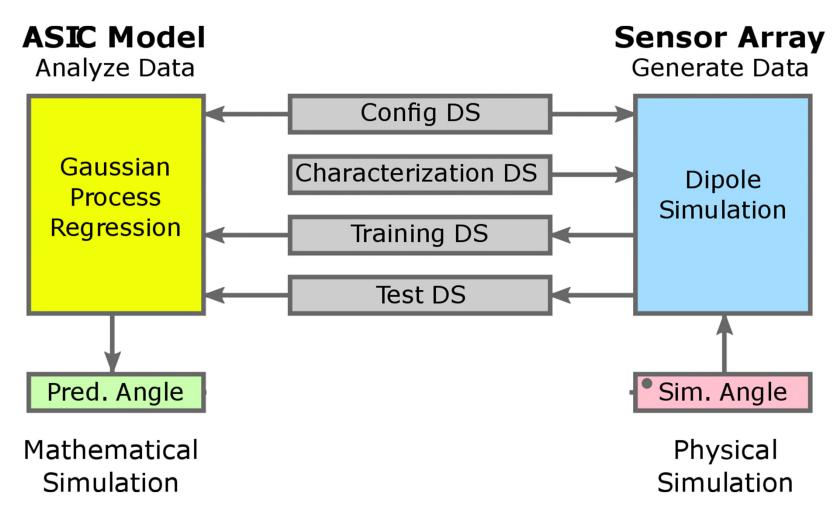




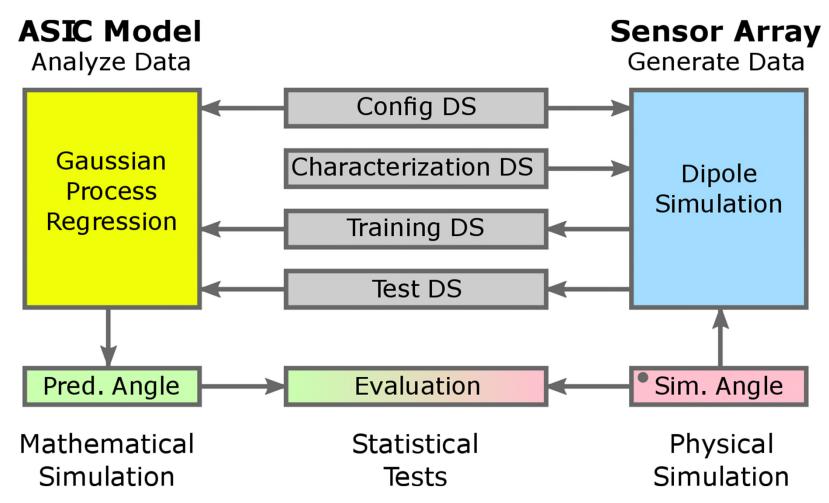






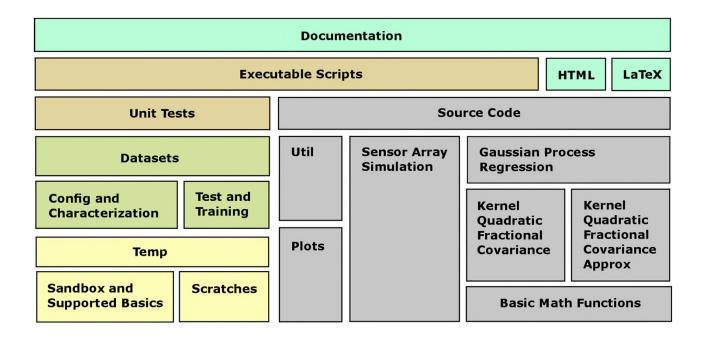






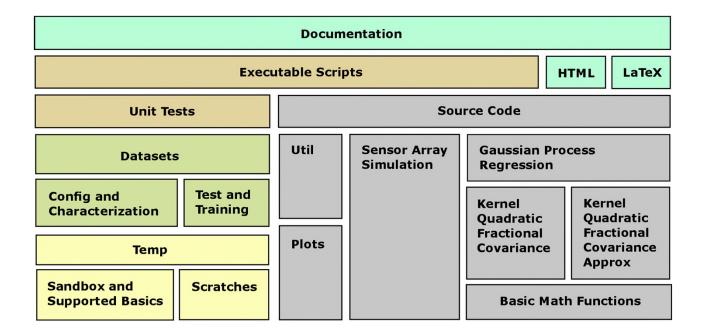


Modularer Aufbau



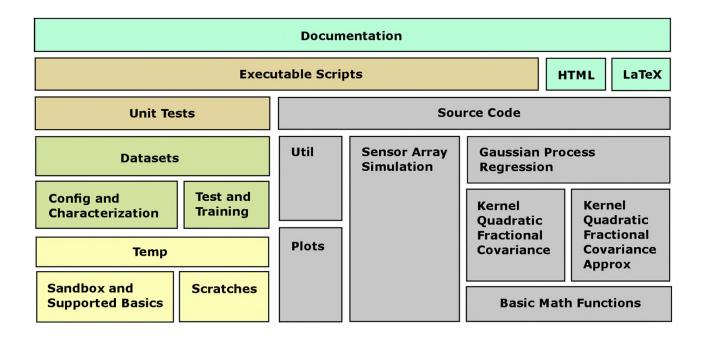


- Modularer Aufbau
- Wiederverwendbarkeit
- Erweiterbarkeit

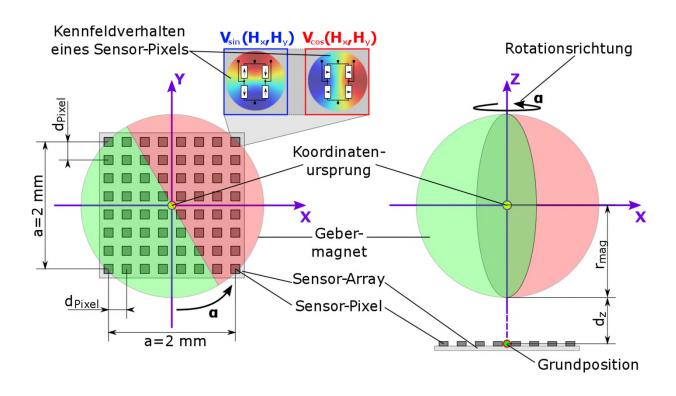




- Modularer Aufbau
- Wiederverwendbarkeit
- Erweiterbarkeit
- Integration
- Dokumentation

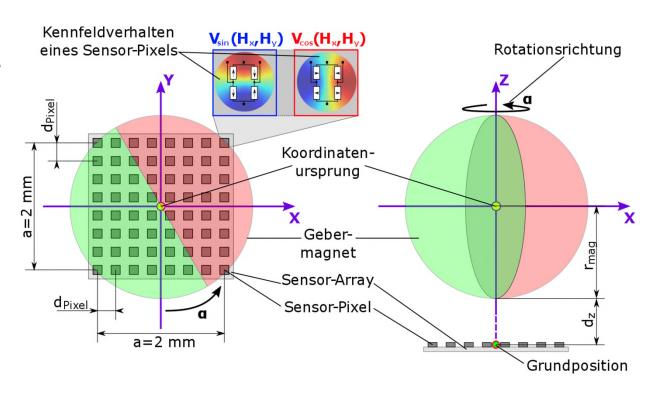






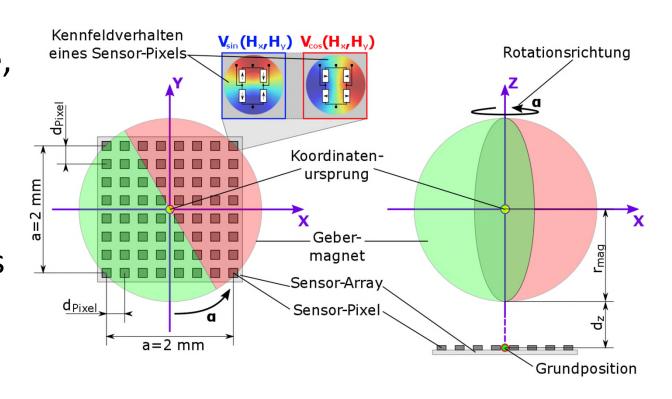


Konfiguration von Abmaße,
 Position, Anordnung und
 Spannungsversorgung

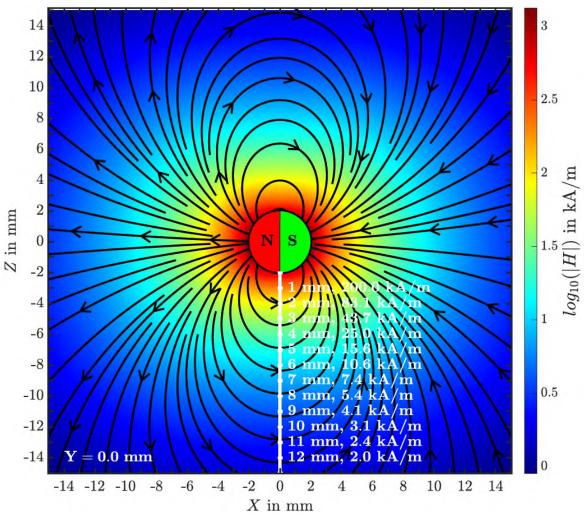




- Konfiguration von Abmaße,
 Position, Anordnung und
 Spannungsversorgung
- Festlegen des Startpunktes bzw. Ruhelage

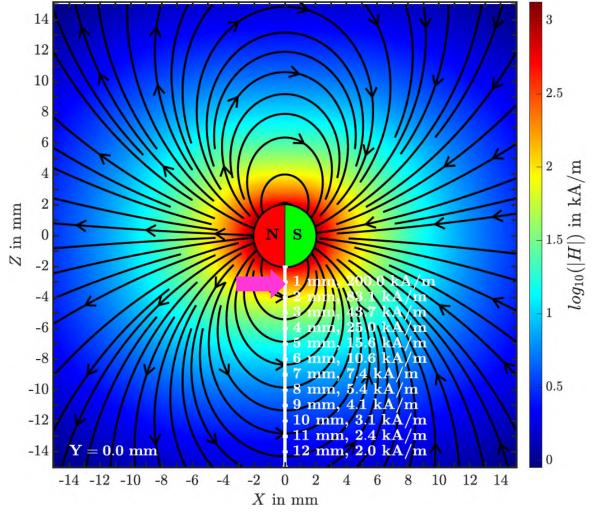






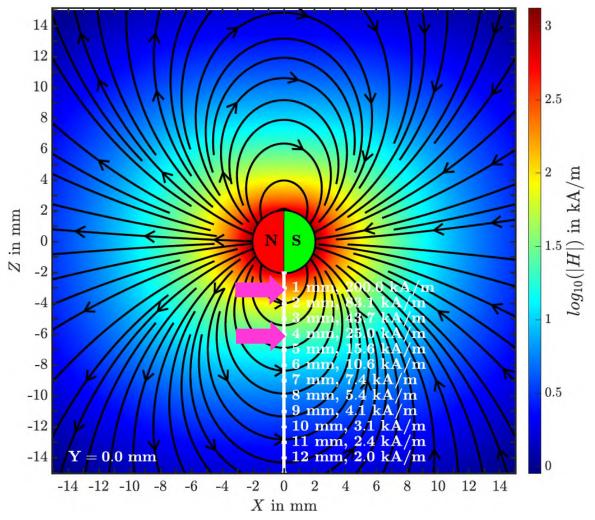


 Konfigurierung der Prägung bei 1 mm und 200 kA/m



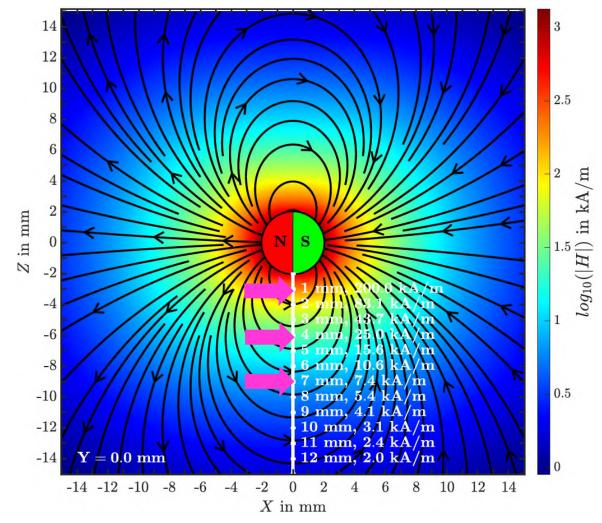


- Konfigurierung der Prägung bei 1 mm und 200 kA/m
- Mindestabstand bei 4 mm und 25 kA/m

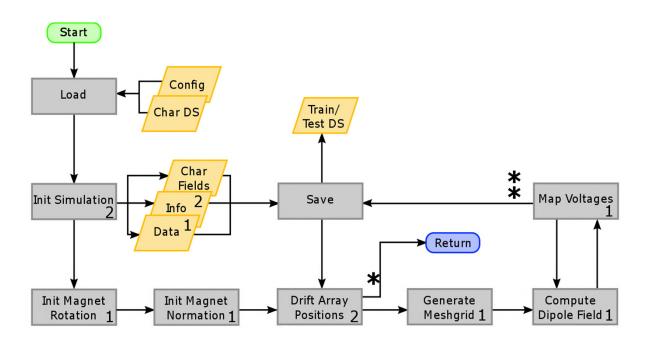




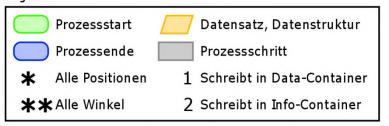
- Konfigurierung der Prägung bei 1 mm und 200 kA/m
- Mindestabstand bei 4 mm und 25 kA/m
- Linearer Bereich bei 7 mm und 7,4 kA/m





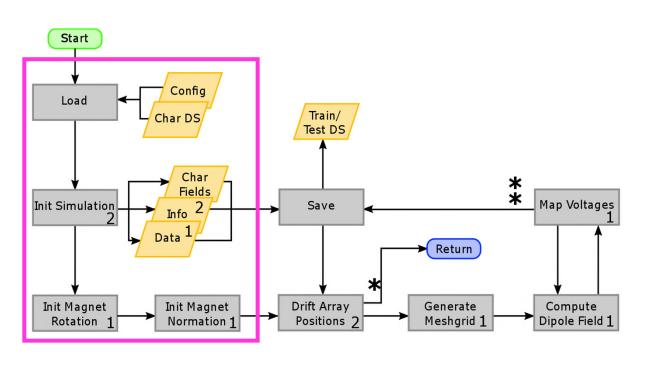


Legende





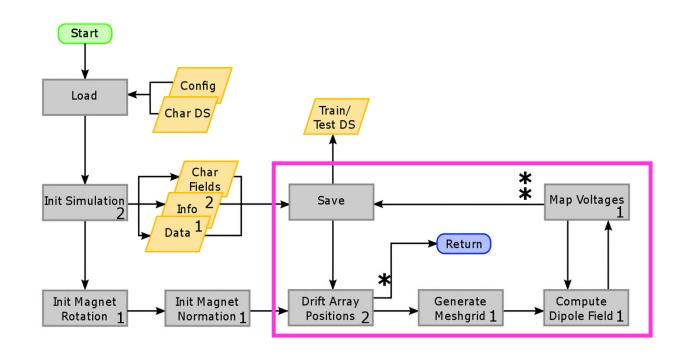
 Laden und initiieren der Simulationsparametern



Prozessstart Datensatz, Datenstruktur Prozessende Prozessschritt Alle Positionen 1 Schreibt in Data-Container **Alle Winkel 2 Schreibt in Info-Container



- Laden und initiieren der Simulationsparametern
- Durchführung in For-Schleifen



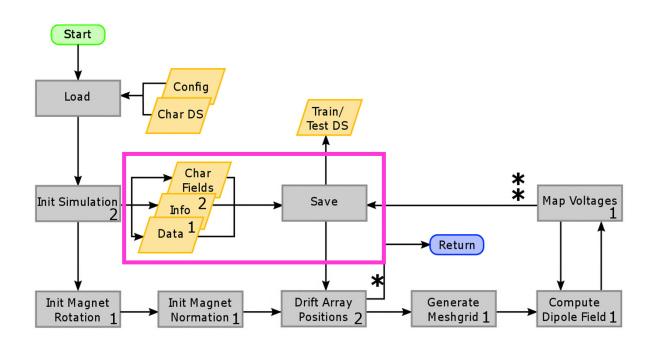
Prozessstart Datensatz, Datenstruktur Prozessende Prozessschritt Alle Positionen 1 Schreibt in Data-Container

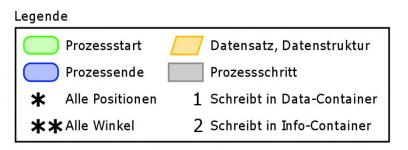
2 Schreibt in Info-Container

** Alle Winkel

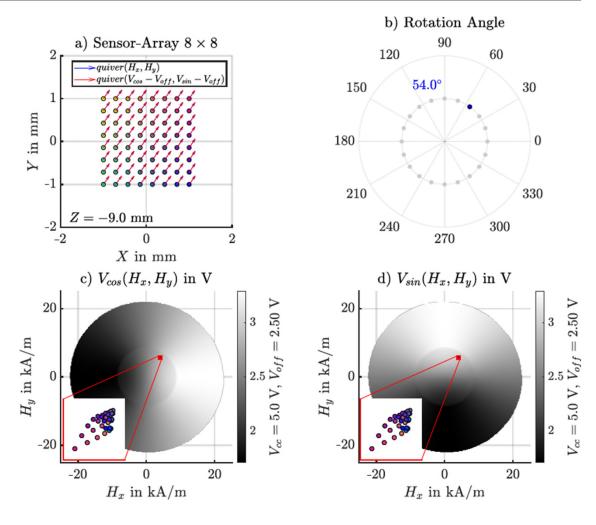


- Laden und initiieren der Simulationsparametern
- Durchführung in For-Schleifen
- Speichern der Datencontainer



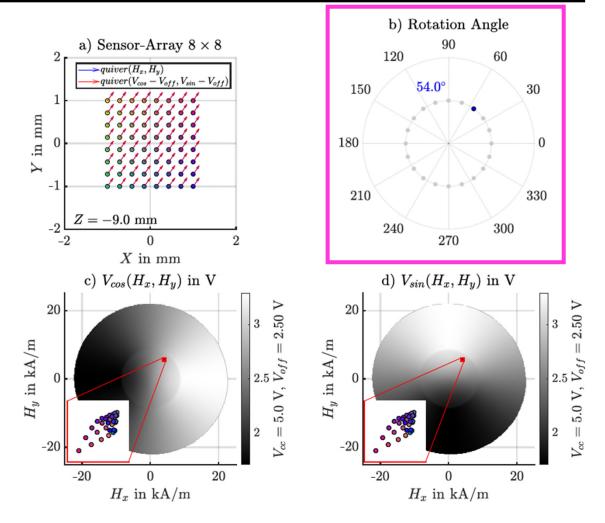






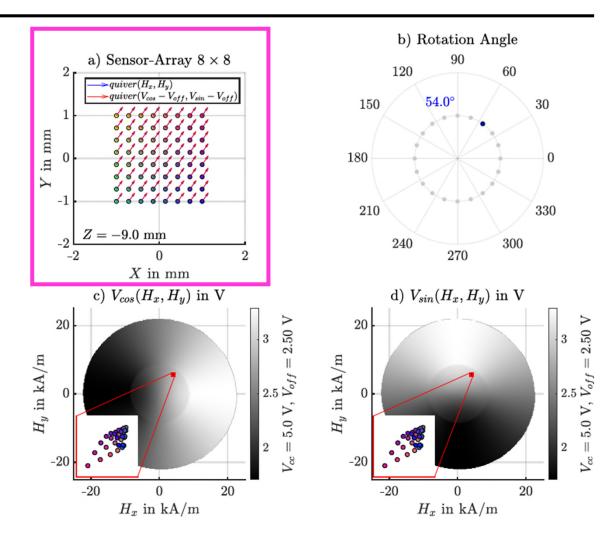


Eingabe – Simulationswinkel





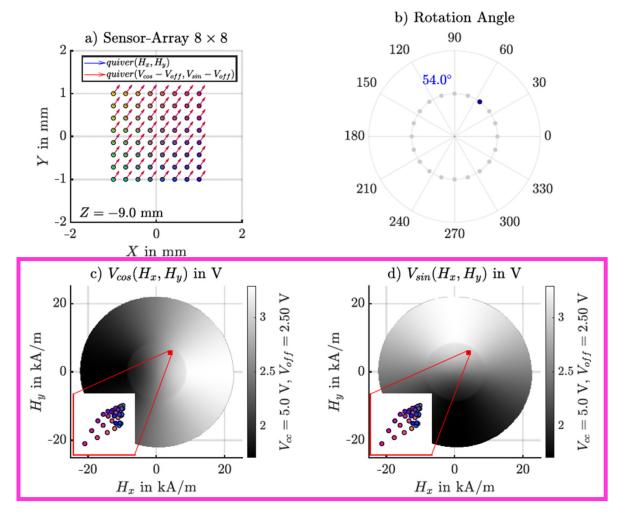
- Eingabe Simulationswinkel
- Meshgird Berechnungen an Sensor-Pixel



Simulation – Sensor-Array



- Eingabe Simulationswinkel
- Meshgird Berechnungen an Sensor-Pixel
- Mapping Entnahme von Referenzspannungen

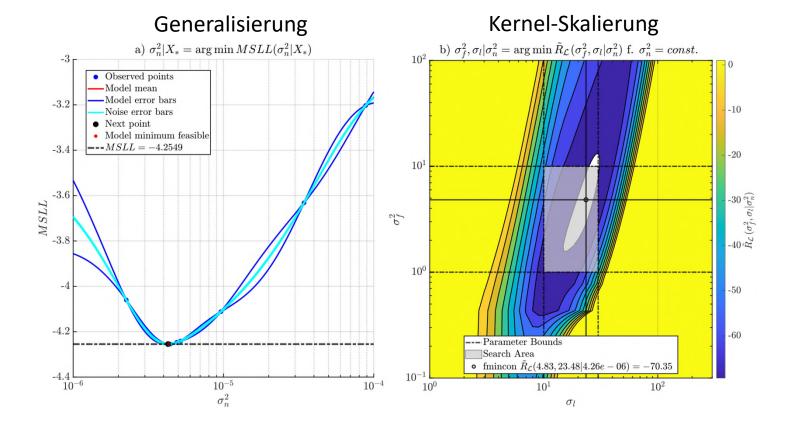




Koniguration



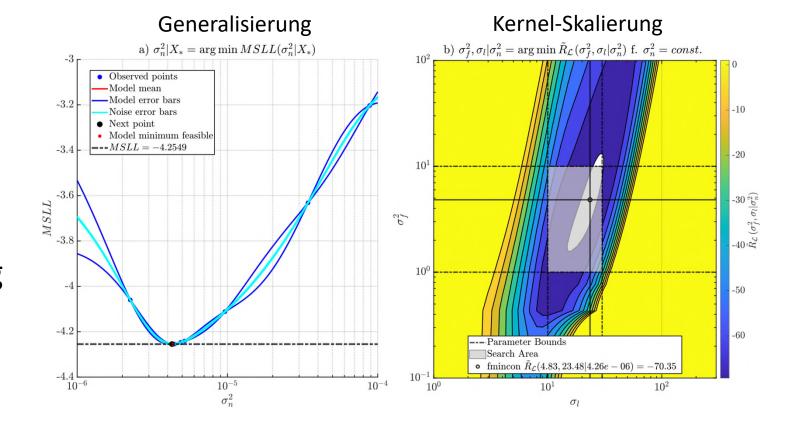
- Koniguration
 - Kernel-Modul
 - Mittelwertbildung



MSLL – Mean-Standardized-Logarithmic-Loss



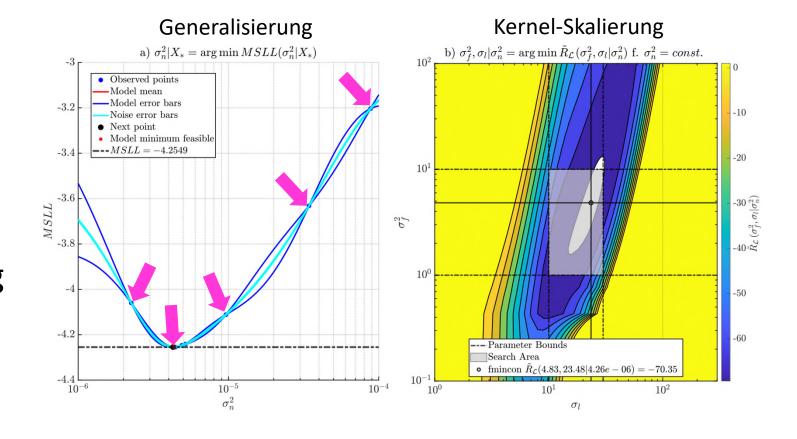
- Koniguration
 - Kernel-Modul
 - Mittelwertbildung
 - Verlustberechnung



MSLL – Mean-Standardized-Logarithmic-Loss



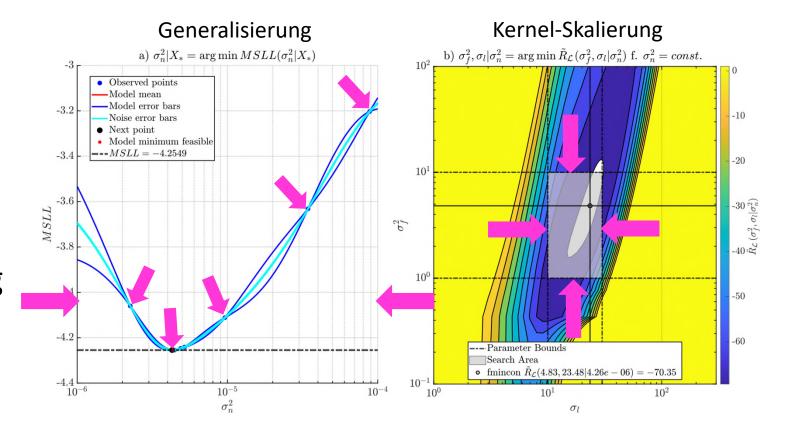
- Koniguration
 - Kernel-Modul
 - Mittelwertbildung
 - Verlustberechnung
 - Durchlaufanzahl



MSLL – Mean-Standardized-Logarithmic-Loss



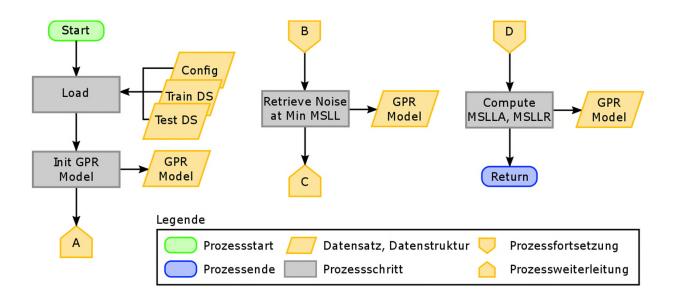
- Koniguration
 - Kernel-Modul
 - Mittelwertbildung
 - Verlustberechnung
 - Durchlaufanzahl
 - Parametergrenzen



MSLL – Mean-Standardized-Logarithmic-Loss



Trainingsphase



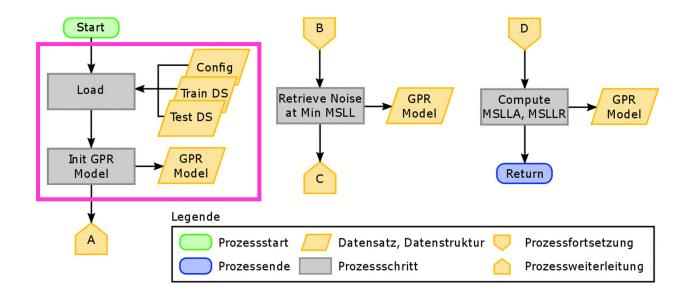
GPR – Gaussian Processes for Regression

MSLL – Mean-Standardized-Logarithmic-Loss

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle



- Trainingsphase
 - Laden und Initialisierung



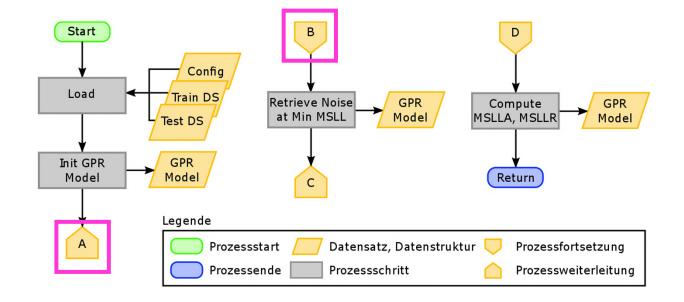
GPR – Gaussian Processes for Regression

MSLL – Mean-Standardized-Logarithmic-Loss

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle



- Trainingsphase
 - Laden und Initialisierung
 - Generalisierung mit eingebetteter Skalierung



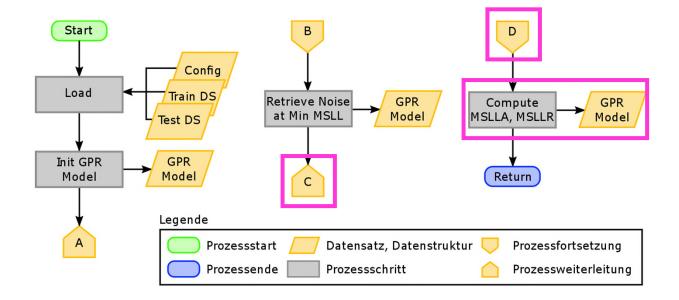
GPR – Gaussian Processes for Regression

MSLL – Mean-Standardized-Logarithmic-Loss

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle



- Trainingsphase
 - Laden und Initialisierung
 - Generalisierung mit eingebetteter Skalierung
 - Finale Skalierung und Bewertung



GPR – Gaussian Processes for Regression

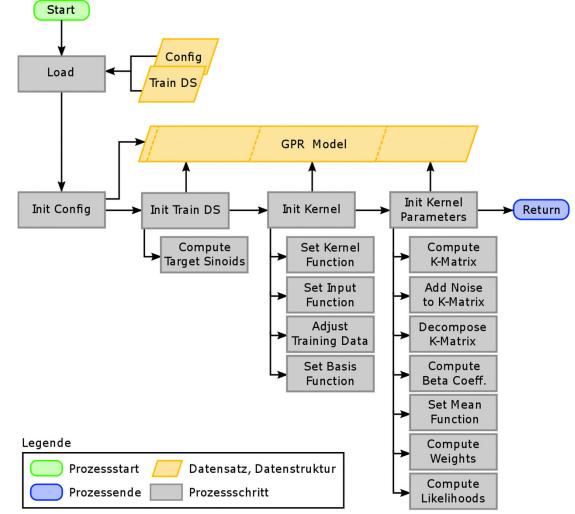
MSLL-Mean-Standardized-Logarithmic-Loss

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle

Simulation − Gauß-Prozesse = HAW BURG



Sequenzielle Initialisierung

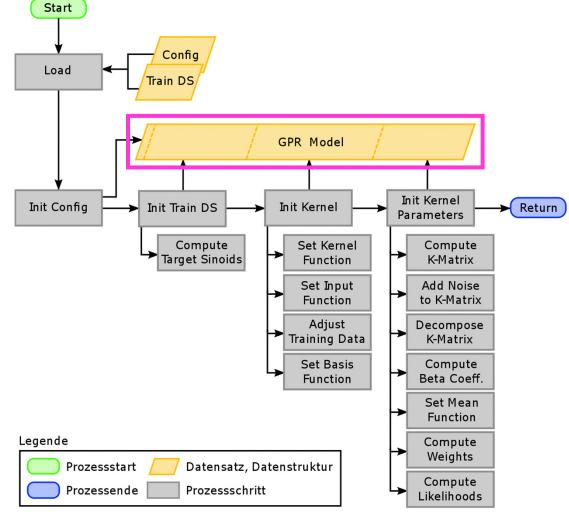


GPR – Gaussian Processes for Regression DS – Dataset

Simulation − Gauß-Prozesse = HAW HAMBURG



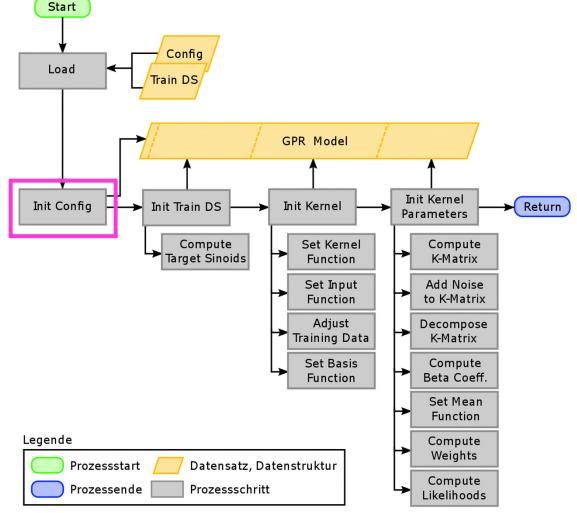
- Sequenzielle Initialisierung
 - Struct-basiertes Modell



GPR – Gaussian Processes for Regression DS – Dataset



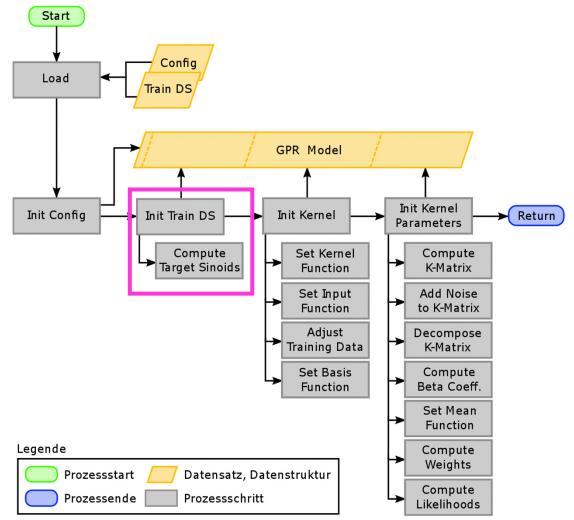
- Sequenzielle Initialisierung
 - Struct-basiertes Modell
 - Konfigurierung Framework



GPR – Gaussian Processes for Regression DS – Dataset

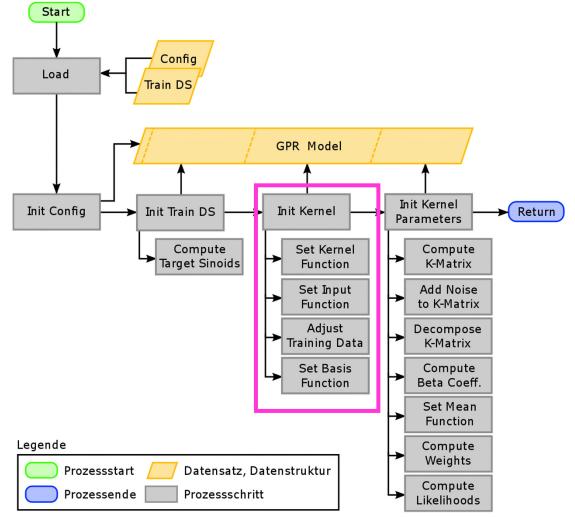


- Sequenzielle Initialisierung
 - Struct-basiertes Modell
 - Konfigurierung Framework
 - Anlegen von Referenzen





- Sequenzielle Initialisierung
 - Struct-basiertes Modell
 - Konfigurierung Framework
 - Anlegen von Referenzen
 - Laden der Funktionalität



GPR – Gaussian Processes for Regression DS – Dataset



Init Kernel

Parameters

Compute

K-Matrix

Add Noise

to K-Matrix

Decompose

K-Matrix

Compute Beta Coeff.

Set Mean Function

Compute Weights

Compute

Likelihoods

- Sequenzielle Initialisierung
 - Struct-basiertes Modell
 - Konfigurierung Framework
 - Anlegen von Referenzen
 - Laden der Funktionalität
 - Modellparametrierung

Legende

Prozessstart

Prozessende

Prozessschritt

Training Data

Set Basis
Function

Punction

Config

Init Train DS

Compute

Target Sinoids

GPR Model

Init Kernel

Set Kernel

Function

Set Input

Function

Adjust

Train DS

GPR – Gaussian Processes for Regression DS – Dataset

Start

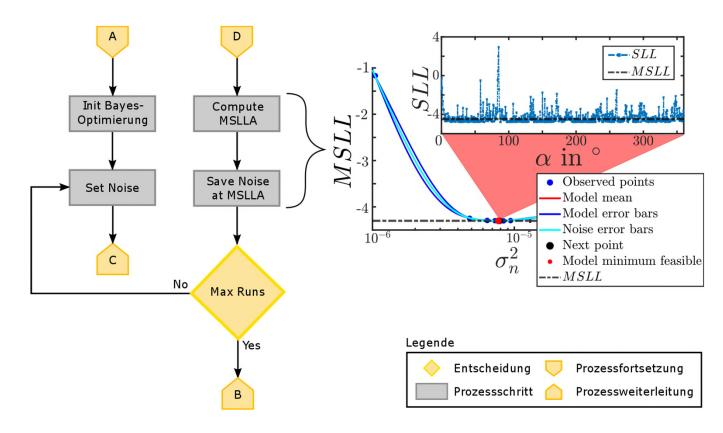
Load

Init Confia

Return



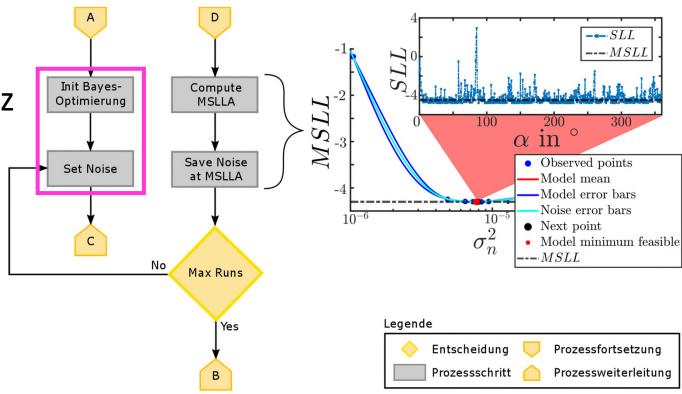
Gernalisierung





Gernalisierung

Setzen der Noise-Varianz

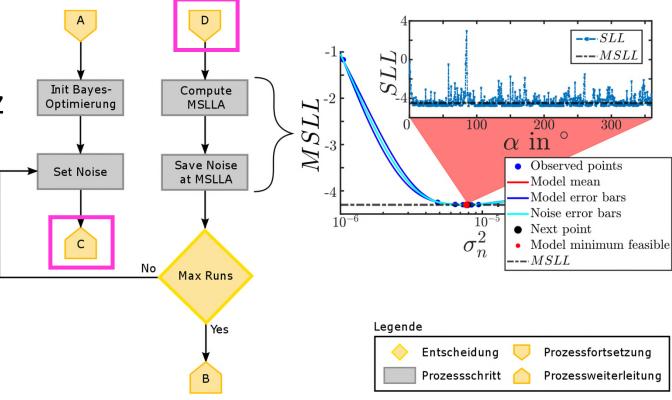




Gernalisierung

Setzen der Noise-Varianz

Kernel-Skalierung

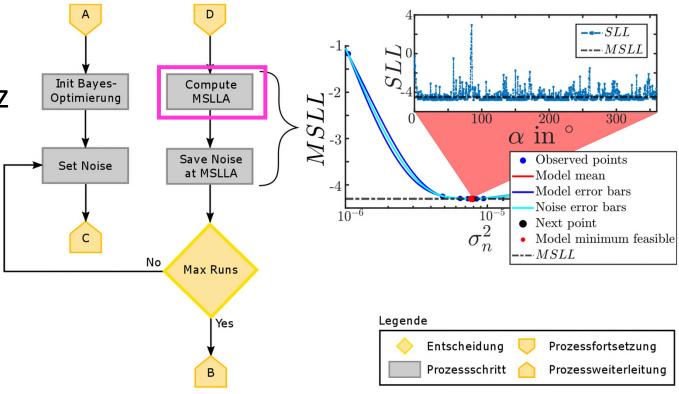




Gernalisierung

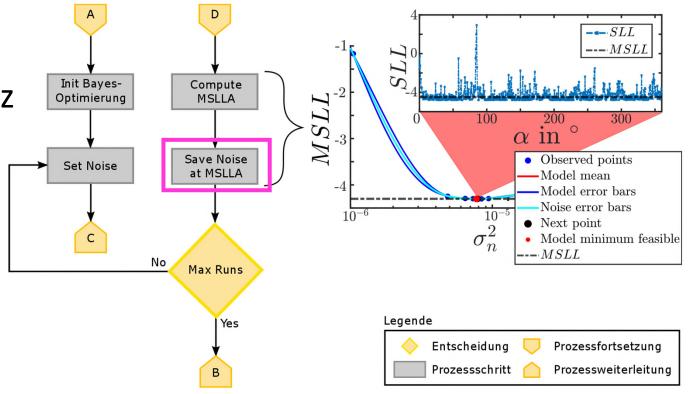
Setzen der Noise-Varianz

- Kernel-Skalierung
- Verlustberechnung



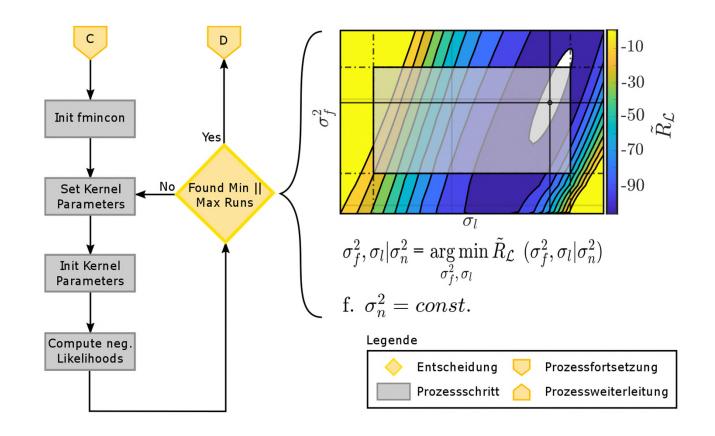


- Gernalisierung
 - Setzen der Noise-Varianz
 - Kernel-Skalierung
 - Verlustberechnung
 - Speichern



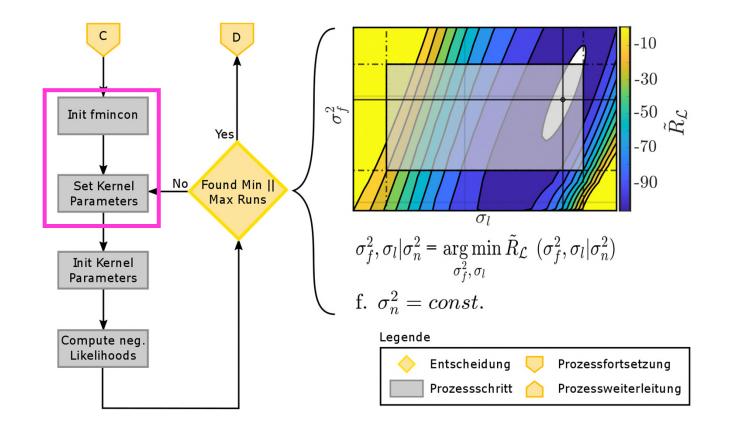


Kernel-Skalierung



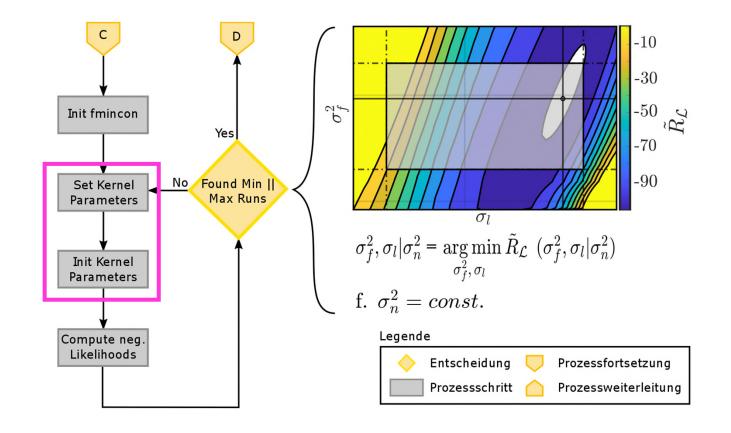


- Kernel-Skalierung
 - Setzen der Parameter



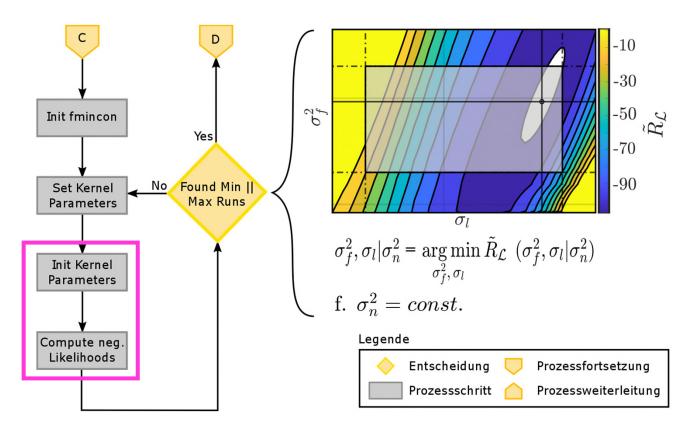


- Kernel-Skalierung
 - Setzen der Parameter
 - Teilreinitialisierung





- Kernel-Skalierung
 - Setzen der Parameter
 - Teilreinitialisierung
 - Plausibilitätsberechnung





Arbeitsphase



- Arbeitsphase
 - Ausrichtung des Modells wird von Innen nach Außen umgelegt

Simulation − Gauß-Prozesse = HAW BURG



- Arbeitsphase
 - Ausrichtung des Modells wird von Innen nach Außen umgelegt
 - Minimale Parametrierung und funktionaler Aufbau der Vorhersage



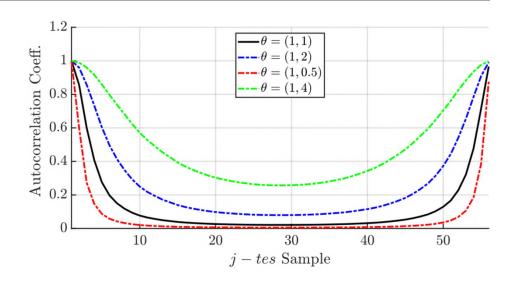
- Arbeitsphase
 - Ausrichtung des Modells wird von Innen nach Außen umgelegt
 - Minimale Parametrierung und funktionaler Aufbau der Vorhersage
 - Vorhersage ausgeführt Frame für Frame oder blockweise



- Arbeitsphase
 - Ausrichtung des Modells wird von Innen nach Außen umgelegt
 - Minimale Parametrierung und funktionaler Aufbau der Vorhersage
 - Vorhersage ausgeführt Frame für Frame oder blockweise
 - Ergebnisse, Derivate und Qualitätskriterien als Vektoren ausgegeben



Skalierung der Kovarianzfunktion





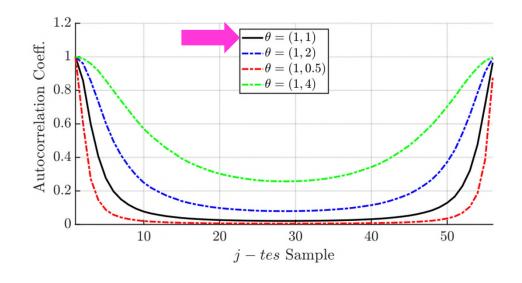
SLLA – Standardized-Logarithmic-Loss-Angle

SLLR - Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle



- Skalierung der Kovarianzfunktion
 - Empirisch ohne Optimierung
 - Bewertung der Generalisierung





SLLA – Standardized-Logarithmic-Loss-Angle

SLLR - Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle



- Skalierung der Kovarianzfunktion
 - Empirisch ohne Optimierung
 - Bewertung der Generalisierung

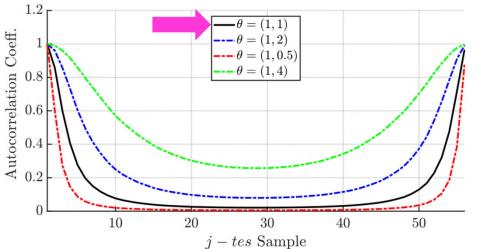
Ausgeschaltet

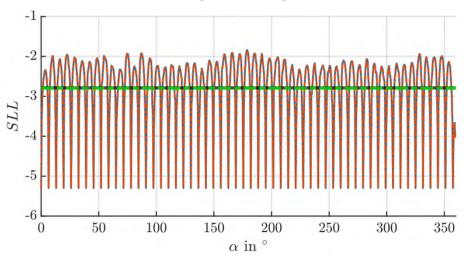


SLLA – Standardized-Logarithmic-Loss-Angle

SLLR – Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle







- Skalierung der Kovarianzfunktion
 - Empirisch ohne Optimierung
 - Bewertung der Generalisierung

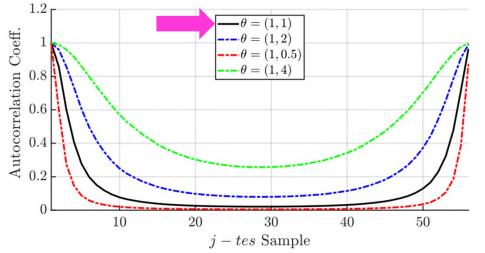
Ausgeschaltet

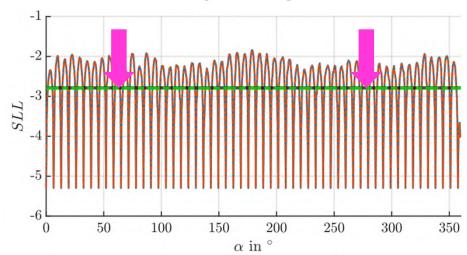


SLLA – Standardized-Logarithmic-Loss-Angle

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MSLLA – Mean-Standardized-Logarithmic-Loss-Angle







- Skalierung der Kovarianzfunktion
 - Empirisch ohne Optimierung
 - Bewertung der Generalisierung

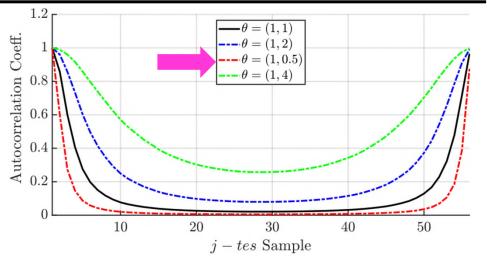
Verschlechtert

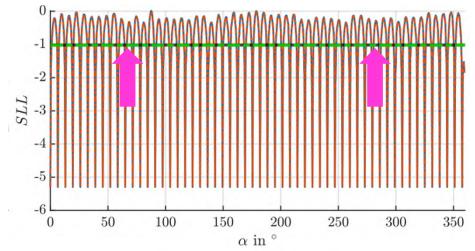


SLLA – Standardized-Logarithmic-Loss-Angle

SLLR - Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle







- Skalierung der Kovarianzfunktion
 - Empirisch ohne Optimierung
 - Bewertung der Generalisierung

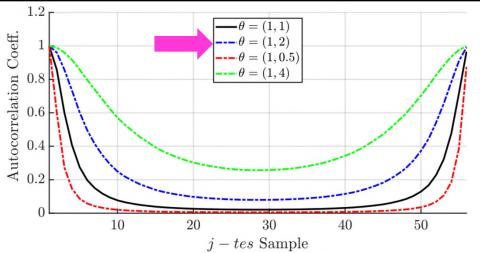
Verbessert

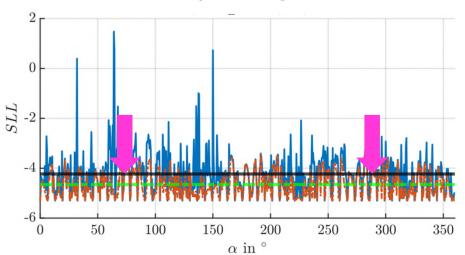


SLLA – Standardized-Logarithmic-Loss-Angle

SLLR - Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle







- Skalierung der Kovarianzfunktion
 - Empirisch ohne Optimierung
 - Bewertung der Generalisierung

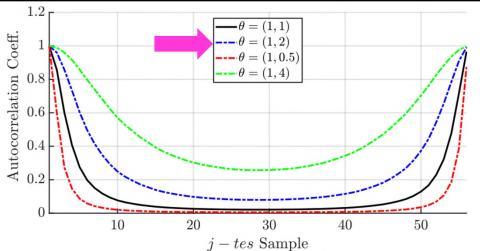
Verbessert

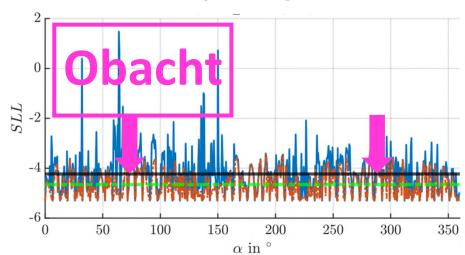


SLLA – Standardized-Logarithmic-Loss-Angle

SLLR – Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle







- Skalierung der Kovarianzfunktion
 - Empirisch ohne Optimierung
 - Bewertung der Generalisierung

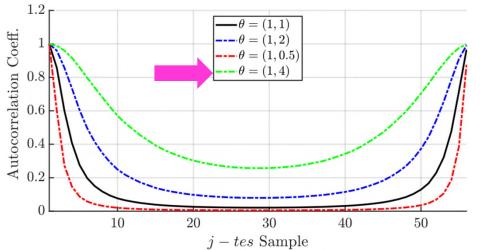
Optimierbar

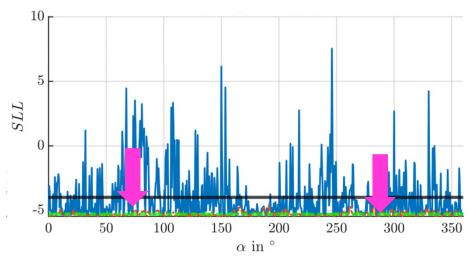


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SLLR - Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle







- Skalierung der Kovarianzfunktion
 - Empirisch ohne Optimierung
 - Bewertung der Generalisierung

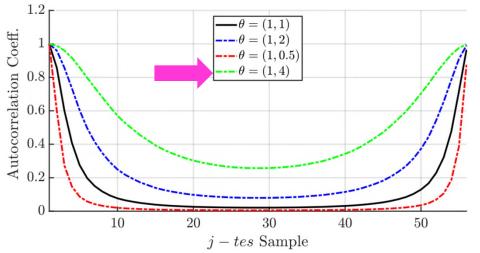
Optimierbar

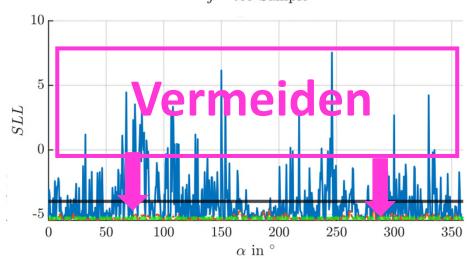


SLLA – Standardized-Logarithmic-Loss-Angle

SLLR - Standardized-Logarithmic-Loss-Radius

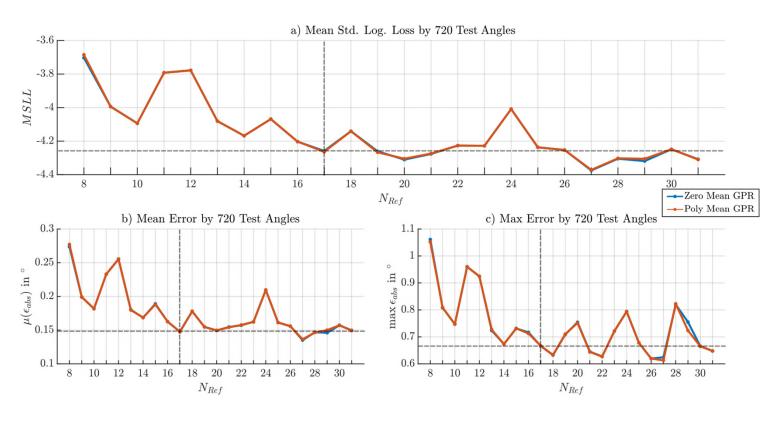
MSLLA – Mean-Standardized-Logarithmic-Loss-Angle







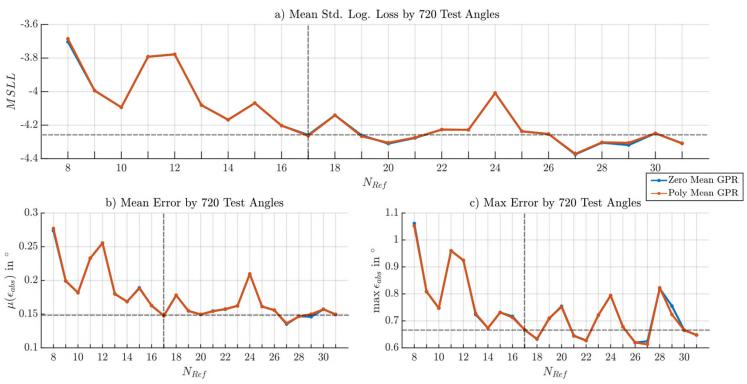
Kompormissbildung



MSLL – Mean-Standardized-Logarithmic-Loss



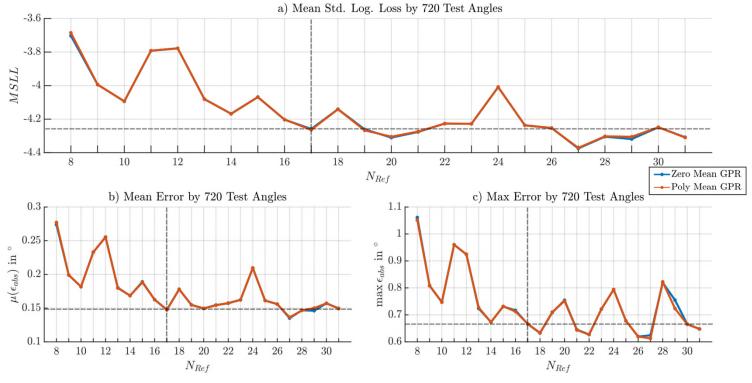
- Kompormissbildung
 - Optimierung zusschalten ^{The state}



MSLL - Mean-Standardized-Logarithmic-Loss



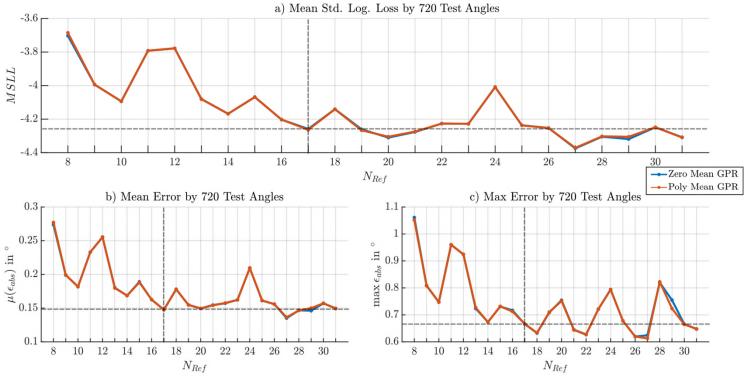
- Kompormissbildung
 - Optimierung zusschalten
 - Ressourceneinsparung



MSLL – Mean-Standardized-Logarithmic-Loss



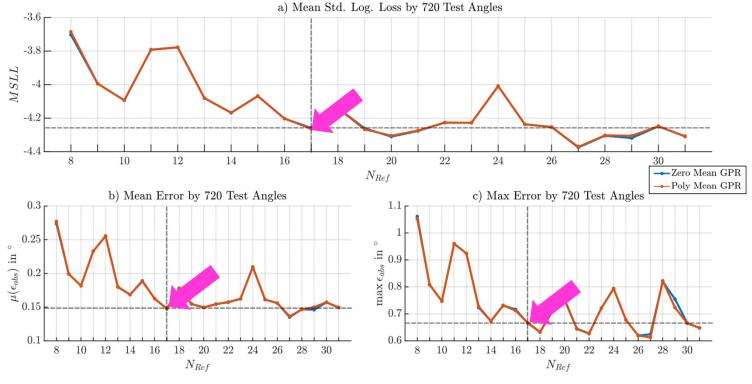
- Kompormissbildung
 - Optimierung zusschalten ^{TS}
 - Ressourceneinsparung
 - Aufwandabschätzung



MSLL - Mean-Standardized-Logarithmic-Loss



- Kompormissbildung
 - Optimierung zusschalten
 - Ressourceneinsparung
 - Aufwandabschätzung
 - Gleichgewicht zwischen
 Fehlern und Verlusten



MSLL – Mean-Standardized-Logarithmic-Loss

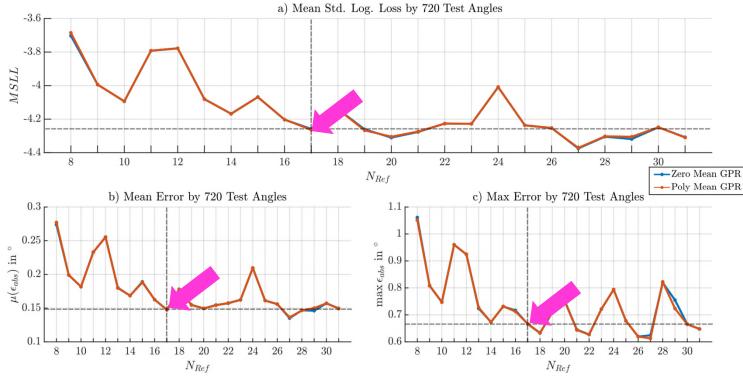


17 Referenzwinkel

- Kompormissbildung
 - Optimierung zusschalten

 Tagen

 Tagen
 - Ressourceneinsparung
 - Aufwandabschätzung
 - Gleichgewicht zwischen
 Fehlern und Verlusten



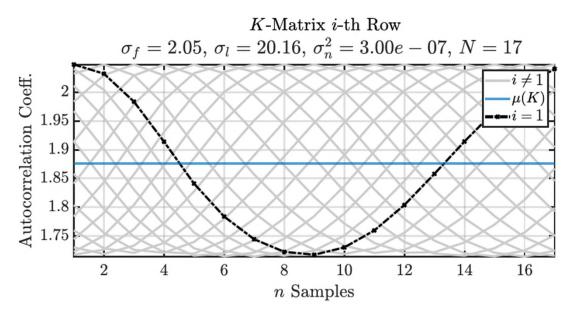
MSLL - Mean-Standardized-Logarithmic-Loss





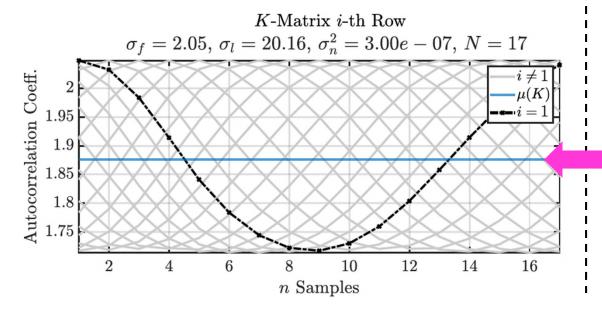
- Verschoben in X-/ Y-Richtung
- Abstand verringert
- Magnet verkippt





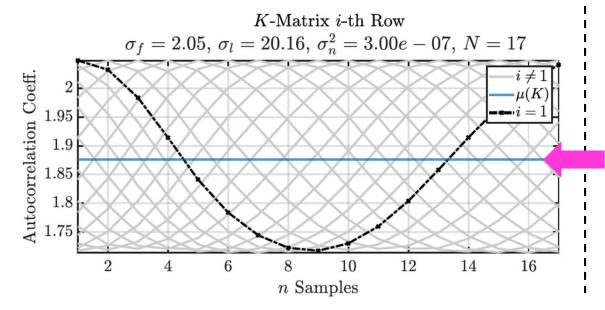
- Verschoben in X-/ Y-Richtung
- Abstand verringert
- Magnet verkippt





- Verschoben in X-/ Y-Richtung
- Abstand verringert
- Magnet verkippt
- Ausgleich zwischen Referenzen



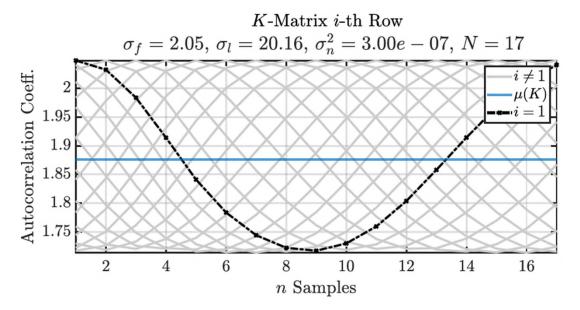


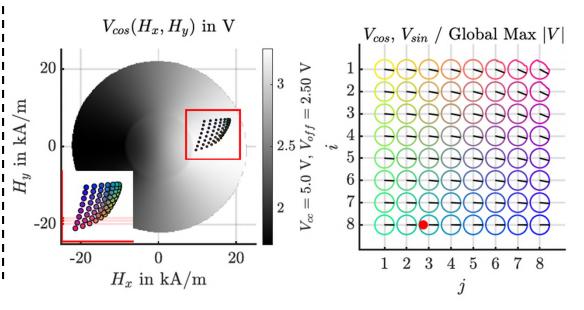
- Verschoben in X-/ Y-Richtung
- Abstand verringert
- Magnet verkippt
- Ausgleich zwischen Referenzen
- Skalierung ca. 1:10

Gute Voraussetzungen

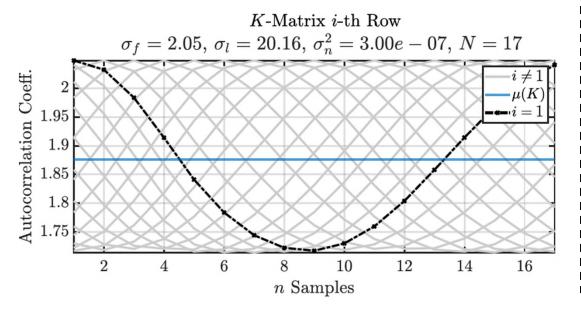


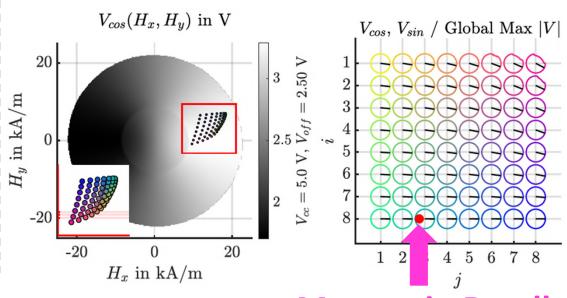
Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°







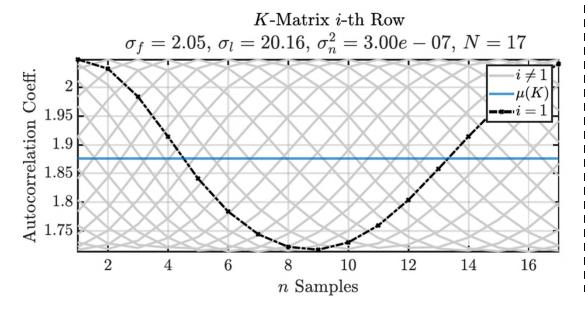




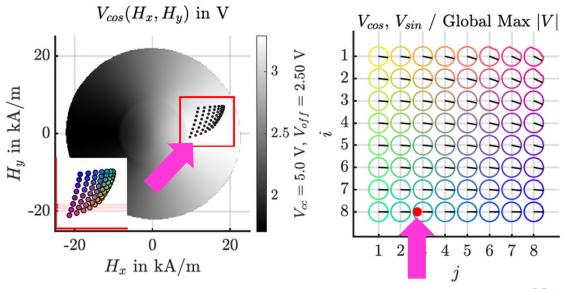
Magnet in Randlag zum Array



Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°



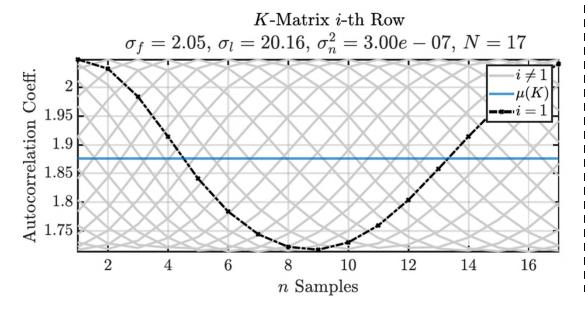
Sättigung + Streuung



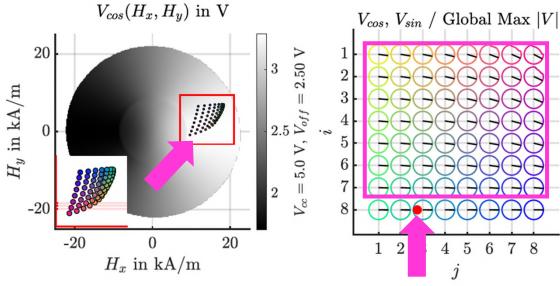
Magnet in Randlag zum Array



Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°



Sättigung + Streuung

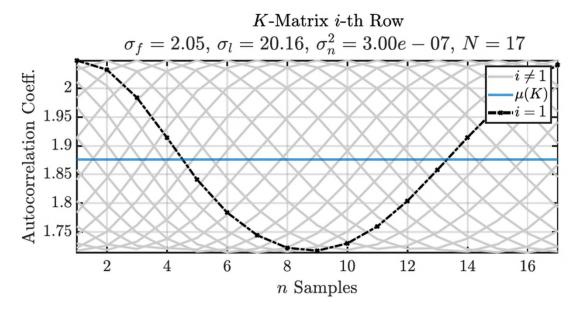


Verfälschte Winkel

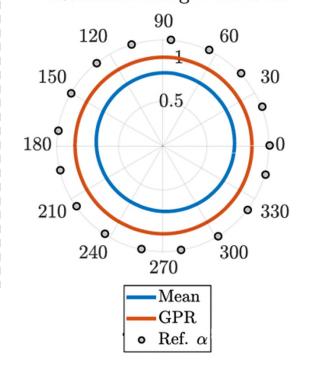
Magnet in Randlag zum Array



Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°

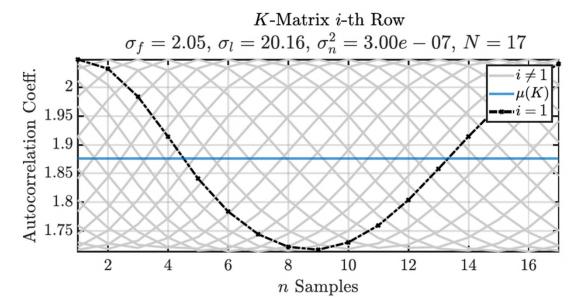


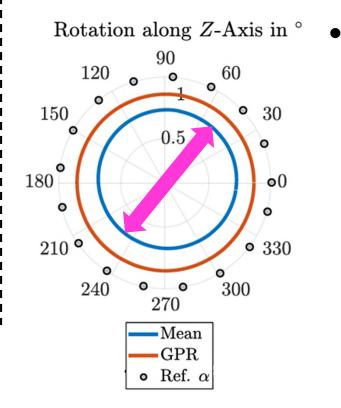
Rotation along Z-Axis in $^{\circ}$





Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°





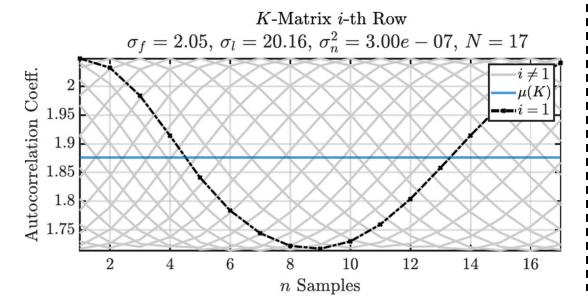
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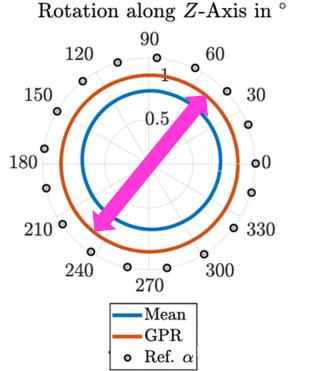
Mittelwert

verschoben



Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°





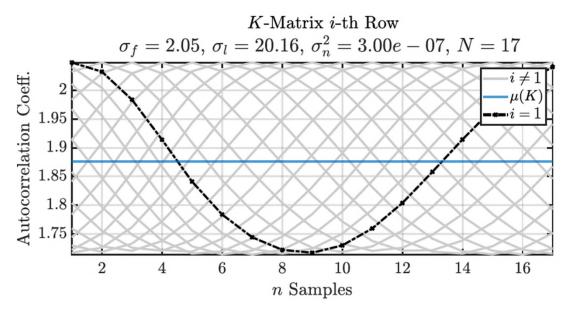
- Einfacher

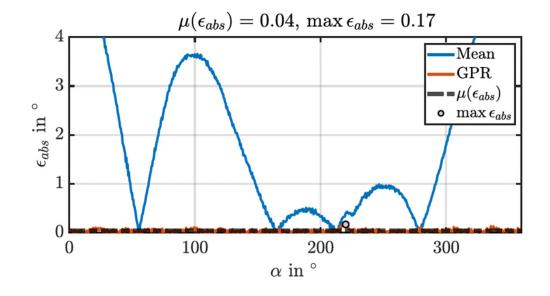
 Mittelwert

 verschoben
- Regression schafft den Ausgleich



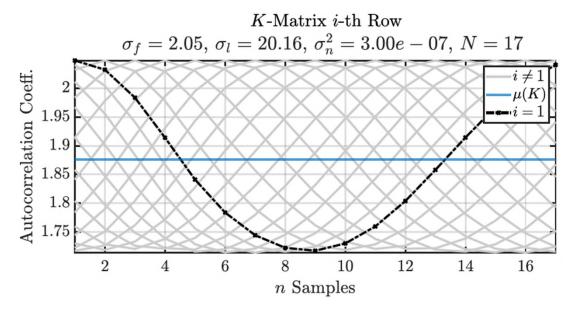
Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°



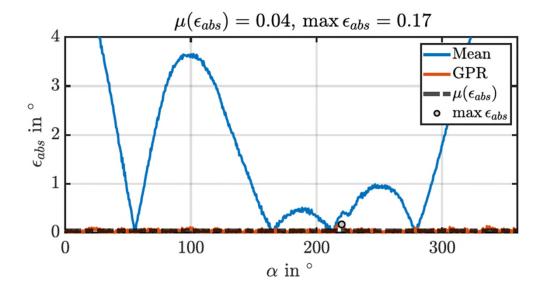




Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°

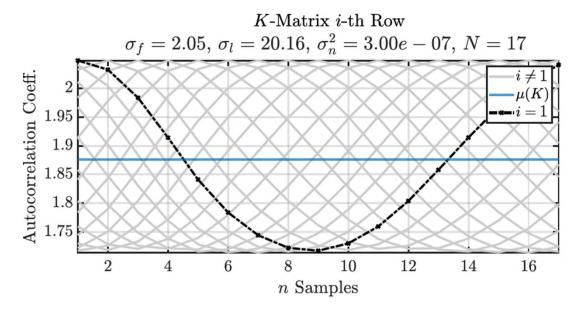


Geringe Winkelfelhler über volle Rotation

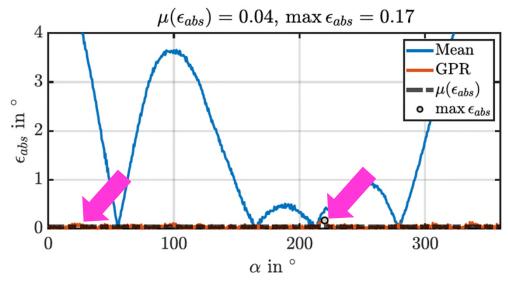




Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°



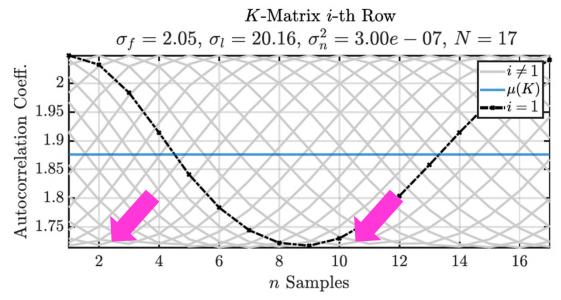
Geringe Winkelfelhler über volle Rotation



Leichte Schwankungen

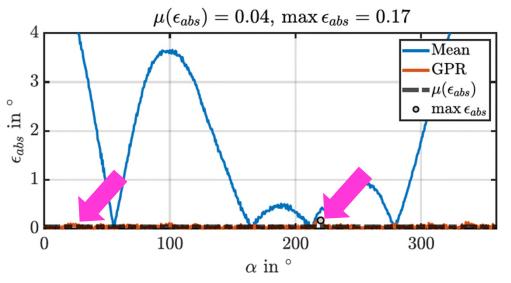


Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°



Leichte Anhebung, Lücke in Abdeckung

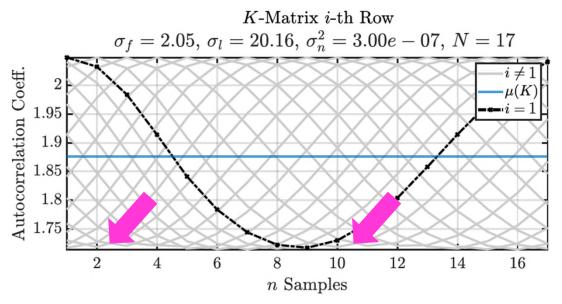
Geringe Winkelfelhler über volle Rotation



Leichte Schwankungen



Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°



Centered 95% GPR Confidence Interval $\times 10^{-3}$ 0.1 0.05 0.05 -0.1 0.100 200 300 $\alpha \text{ in } ^{\circ}$

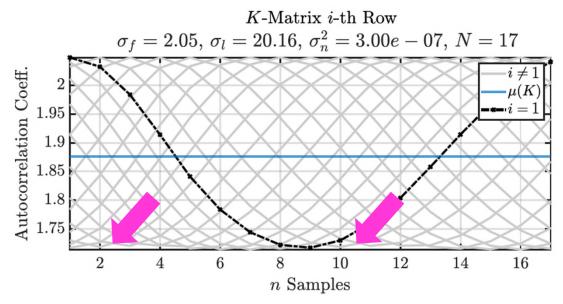
Leichte Anhebung, Lücke in Abdeckung

Hohes Vertrauen, enge Intervalle

CIA – Confidence-Interval-Angle CIR – Confidence-Interval-Radius

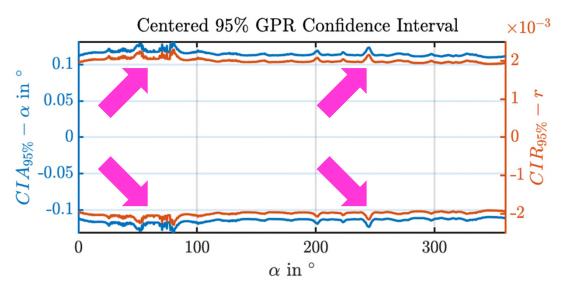


Position: (0.5, 1.0, 4.5)^T mm, Tilt: 11.0°



Leichte Anhebung, Lücke in Abdeckung

Anzeige der Abdeckungslücke

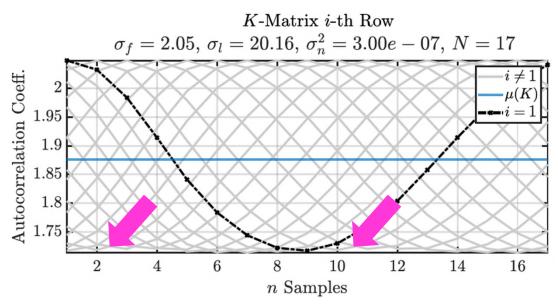


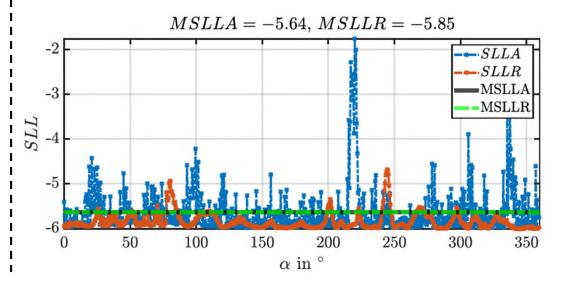
Hohes Vertrauen, enge Intervalle

CIA – Confidence-Interval-Angle CIR – Confidence-Interval-Radius



Position: $(0.5, 1.0, 4.5)^T$ mm, Tilt: 11.0°





Leichte Anhebung, Lücke in Abdeckung

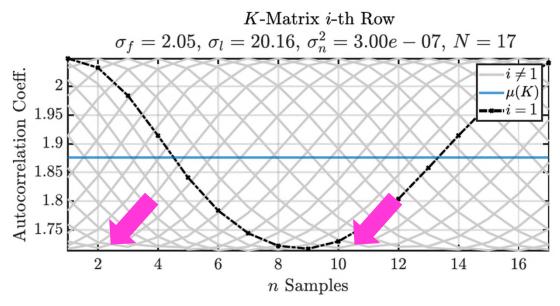
SLLA – Standardized-Logarithmic-Loss-Angle

SLLR – Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle



Position: $(0.5, 1.0, 4.5)^T$ mm, Tilt: 11.0°



Leichte Anhebung, Lücke in Abdeckung

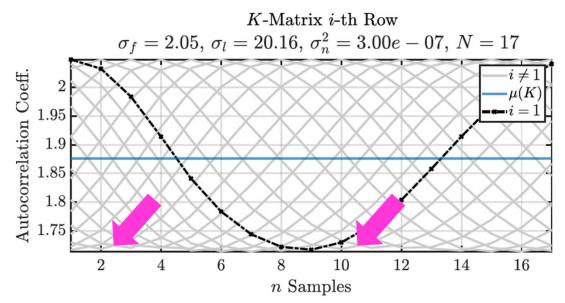
Starke Generalisierung

SLLA – Standardized-Logarithmic-Loss-Angle SLLR – Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle

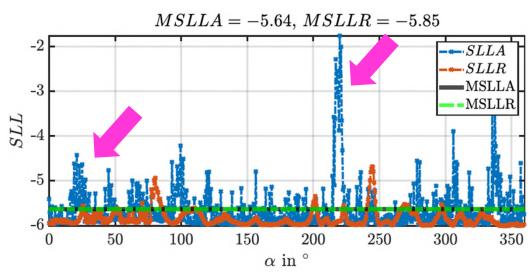


Position: $(0.5, 1.0, 4.5)^T$ mm, Tilt: 11.0°



Leichte Anhebung, Lücke in Abdeckung

Abdeckungslücke schwächt Generalisierung



Starke Generalisierung

SLLA - Standardized-Logarithmic-Loss-Angle

SLLR - Standardized-Logarithmic-Loss-Radius

MSLLA – Mean-Standardized-Logarithmic-Loss-Angle



Erreichtes



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 - Simulations-Framework
 - Erweiterbarkeit



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Ende



Vielen Dank!