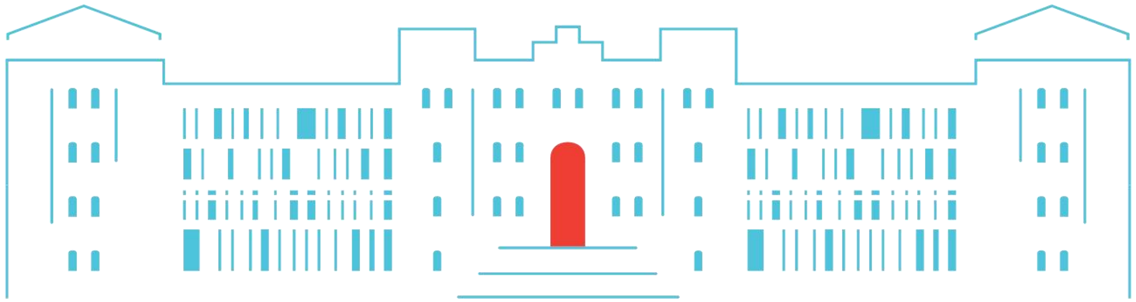
EMC Forum

SDU University of Southern Denmark

Adaptive On-the-Fly Near-Field Scanning via Gaussian Process Regression and Bayesian Optimization

TUHH Hamburg University of Technology



Cheng Yang, 29 Jun. 2026 | Sønderborg, DK

Content

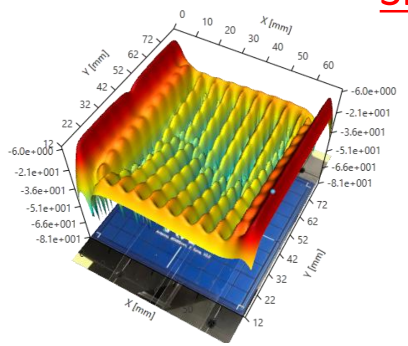
I. Introduction

TUHH
TET

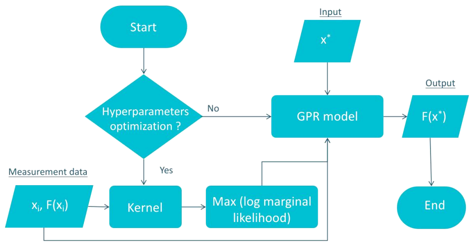
Abstract: Advancements in wireless communication, quantum computing, and electric vehicles are introducing significant challenges for electrical and microwave engineering, particularly in addressing electromagnetic compatibility (EMC). **Near-field measurement**, as a cost-effective and practical solution, is therefore widely applied for pre-compliance testing, especially when full wave modeling and simulation become infeasible. This talk presents an adaptive near-field acquisition framework based on iterative, **on-the-fly (OTF) scanning guided by Gaussian process regression and Bayesian optimization**. The proposed approach enables **high-speed, high-resolution near-field measurements for large-scale EMC applications**. Experimental demonstrations using both industrial-grade and educational robotic platforms across a range of devices illustrate how fast, intelligent near-field measurements can now be completed within minutes. The methodology is further extended to support cost-effective indoor and outdoor EMC and antenna measurements at GHz frequencies.

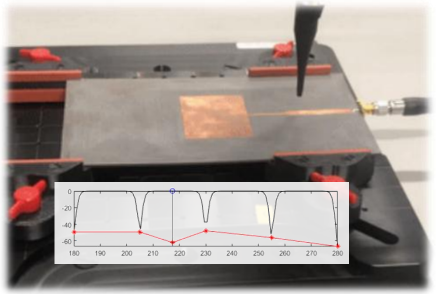
I. Introduction

- **Robotic near-field scan @ TET (research -> engineering)**



Smarter





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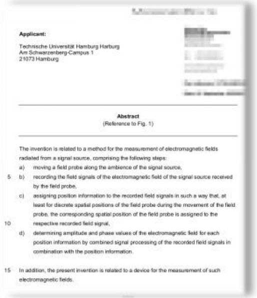
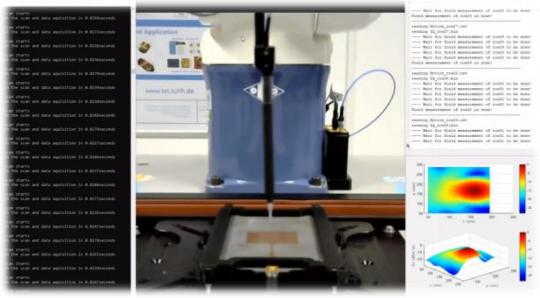


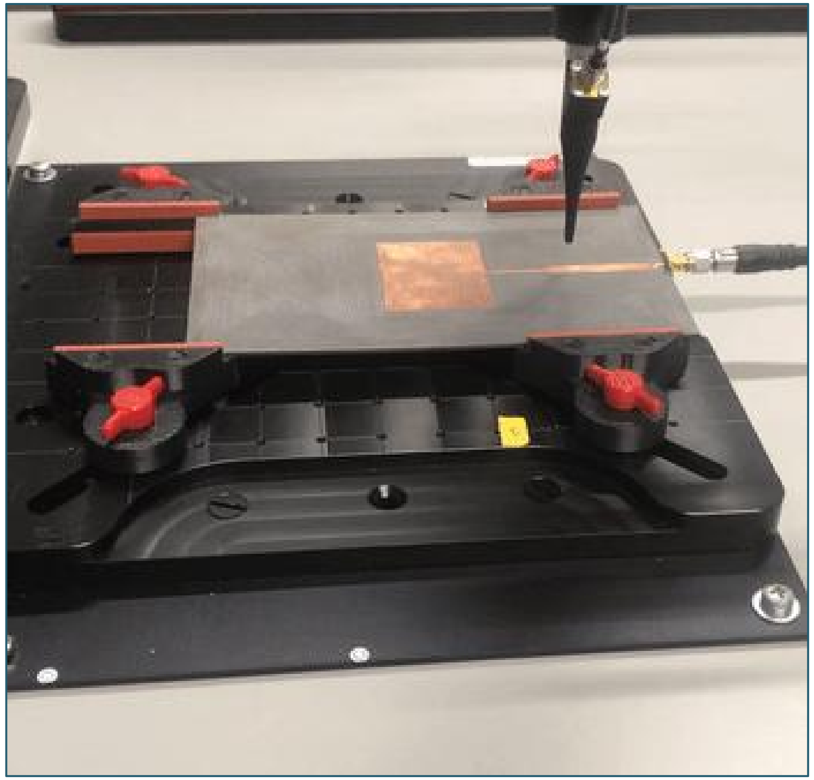


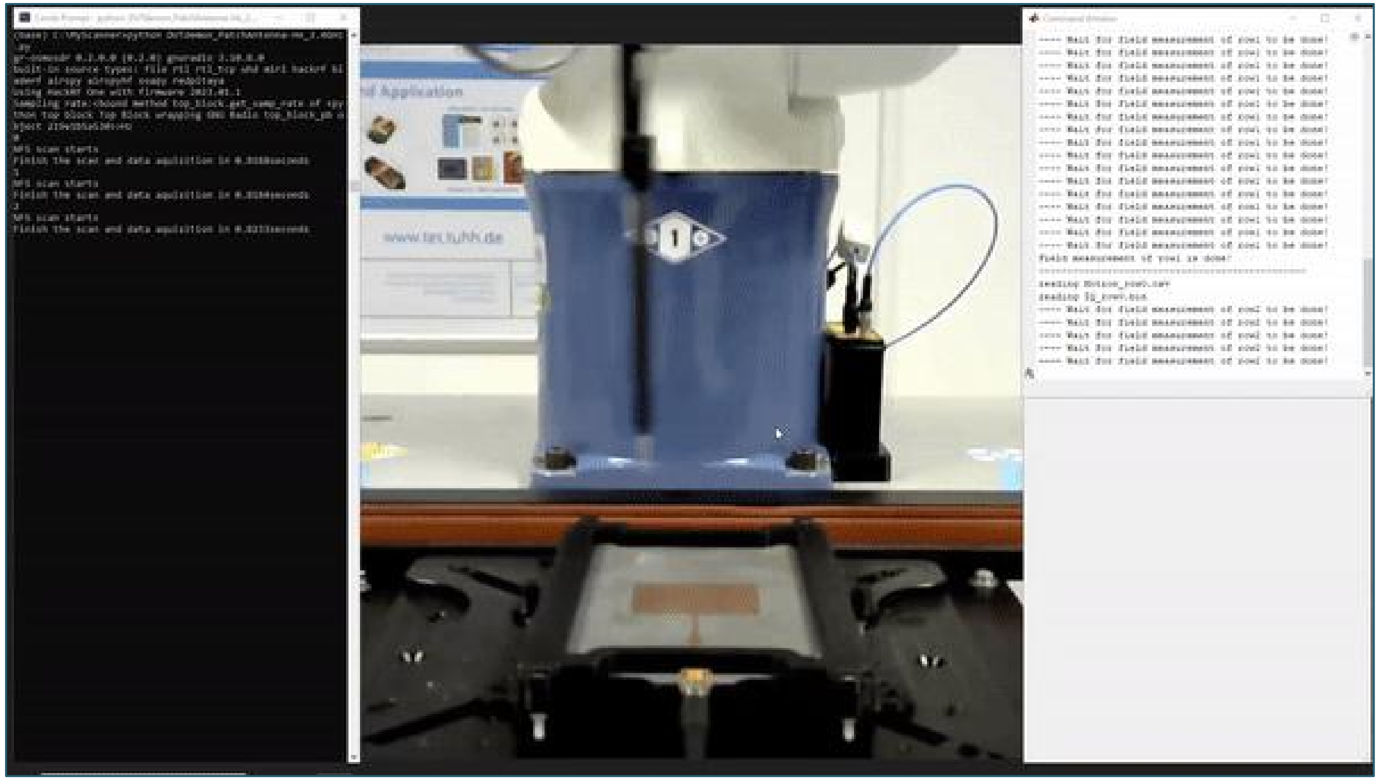
Adaptive

2021 — 2022-2023 — 2024-

I. Introduction

- **Motivation and novelty: Breaking the Speed–Resolution Barrier**

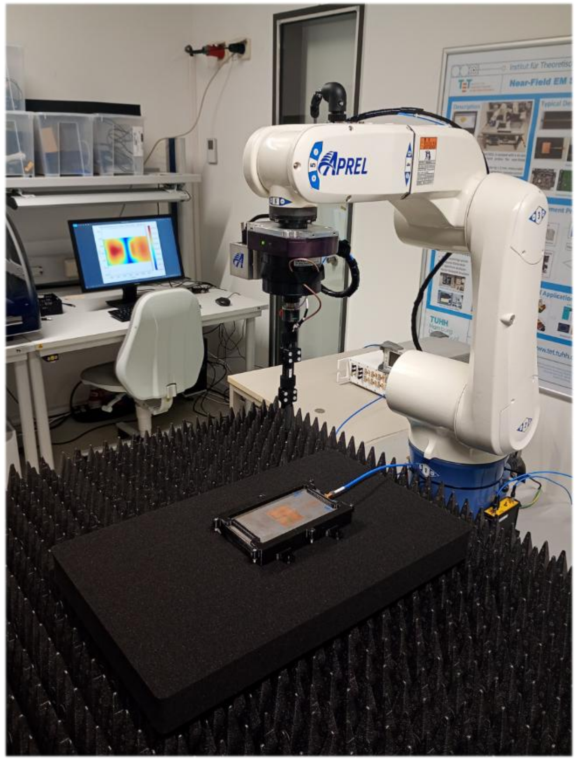


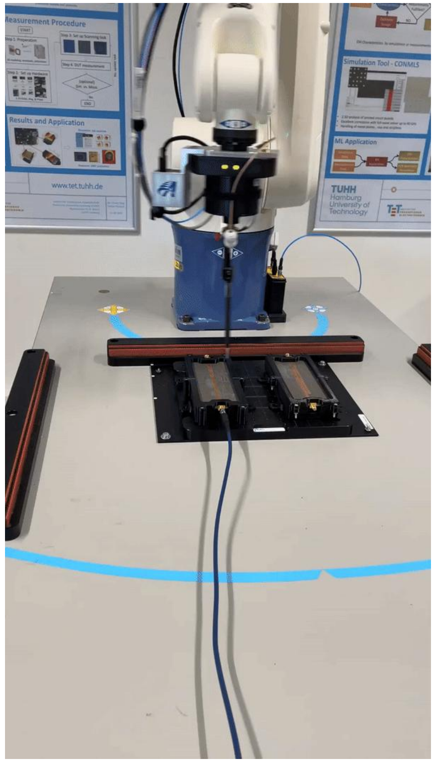
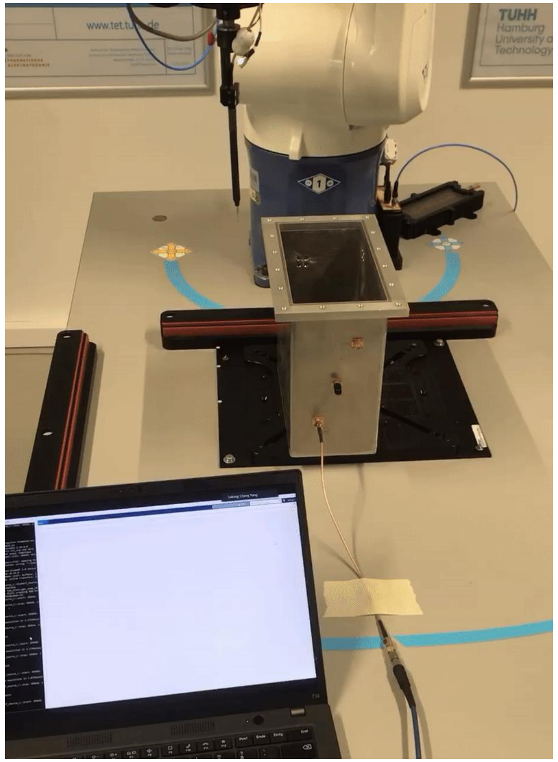
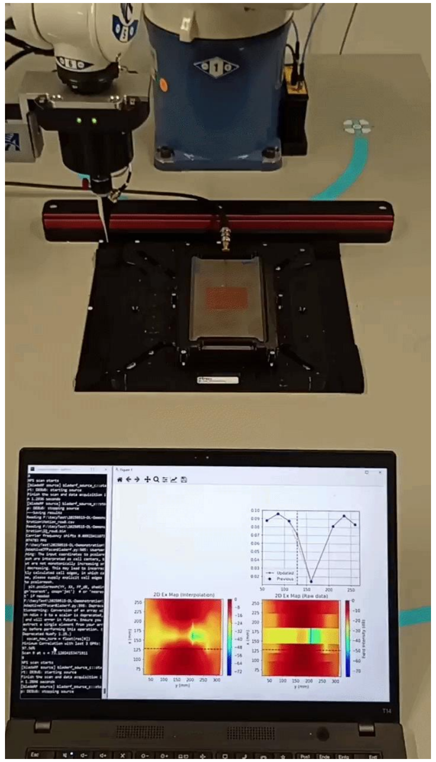


Step-scan (left) & on-the-fly scan (right) of a patch antenna at GHz frequencies

I. Introduction

- **Demonstrations using an industry robot arm**

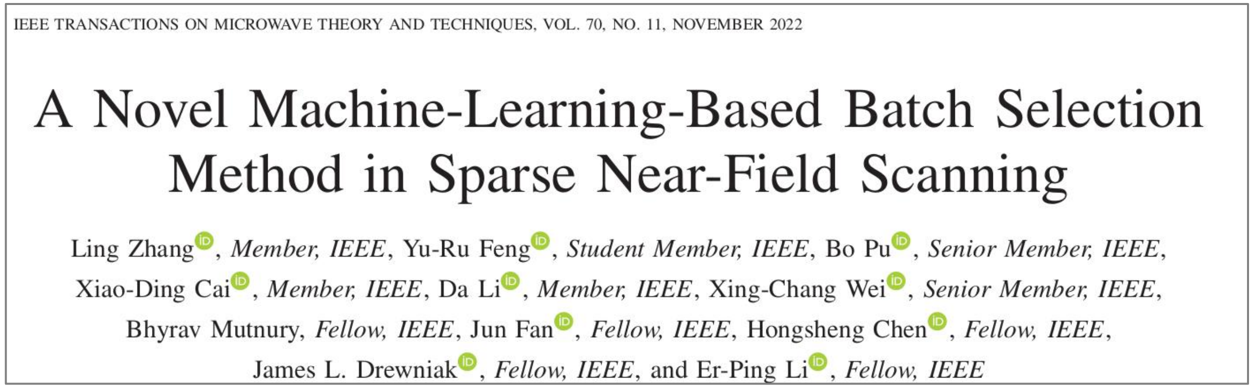


Content

II. Methodology

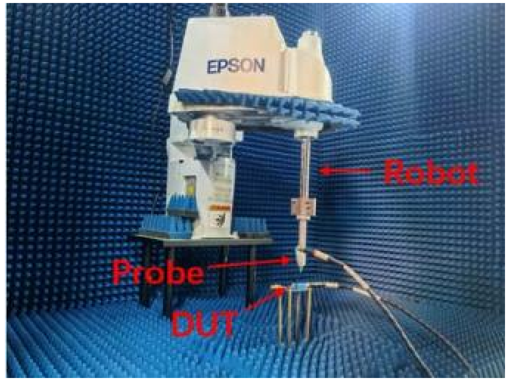
- **State of the art: Adaptive near-field scans ***



IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 70, NO. 11, NOVEMBER 2022

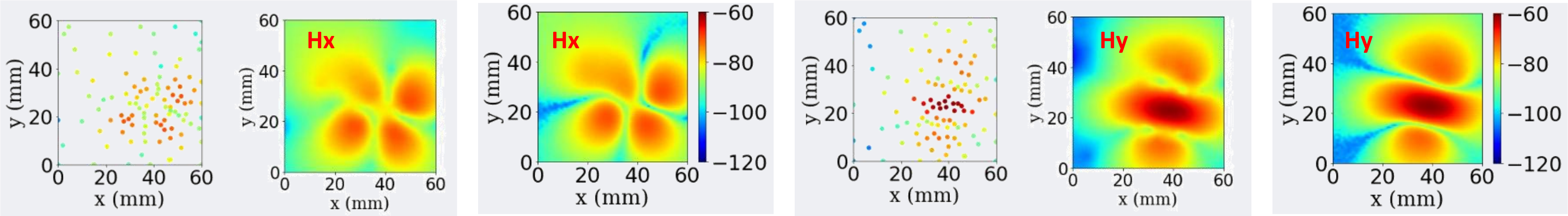
A Novel Machine-Learning-Based Batch Selection Method in Sparse Near-Field Scanning

Ling Zhang, *Member, IEEE*, Yu-Ru Feng, *Student Member, IEEE*, Bo Pu, *Senior Member, IEEE*, Xiao-Ding Cai, *Member, IEEE*, Da Li, *Member, IEEE*, Xing-Chang Wei, *Senior Member, IEEE*, Bhyrav Mutnury, *Fellow, IEEE*, Jun Fan, *Fellow, IEEE*, Hongsheng Chen, *Fellow, IEEE*, James L. Drewniak, *Fellow, IEEE*, and Er-Ping Li, *Fellow, IEEE*



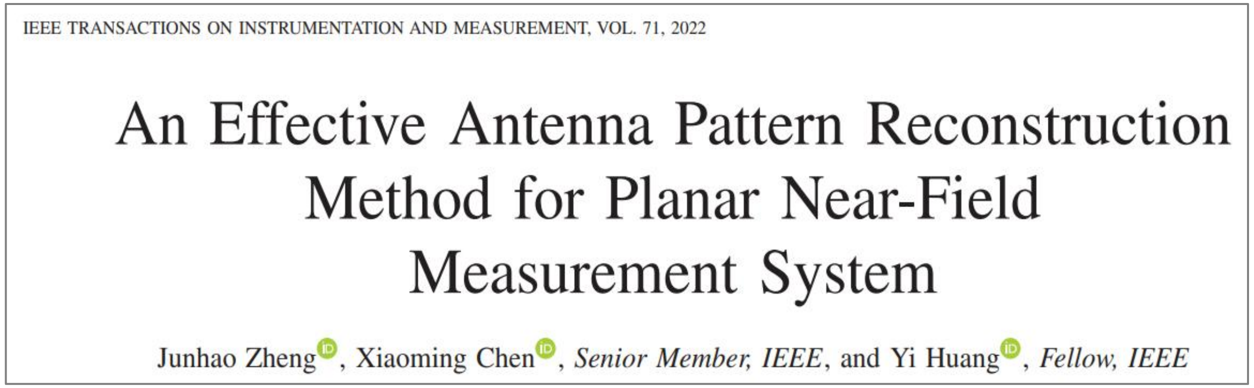
Task: 2D H-field scan

Points: 14.6 k >> 0.1 k



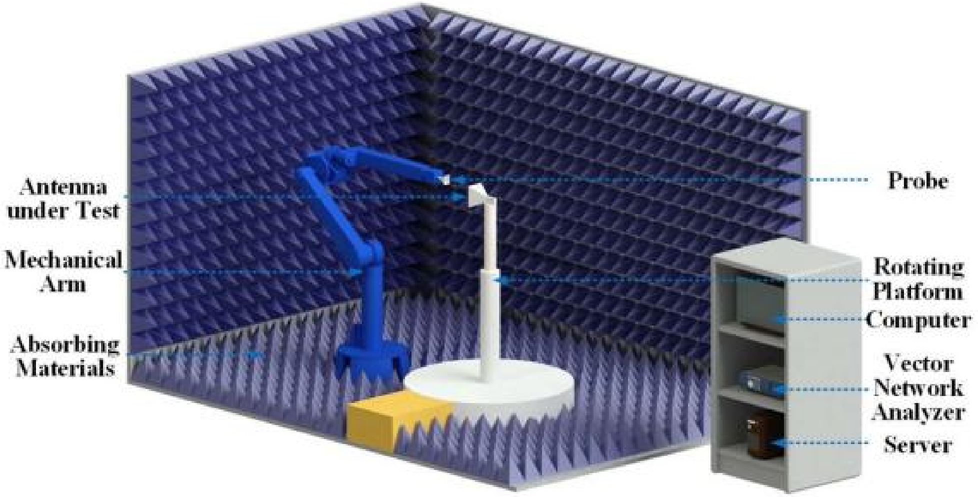
* L. Zhang et al., "A Novel Machine-Learning-Based Batch Selection Method in Sparse Near-Field Scanning," 2022, doi: 10.1109/TMTT.2022.3205909.

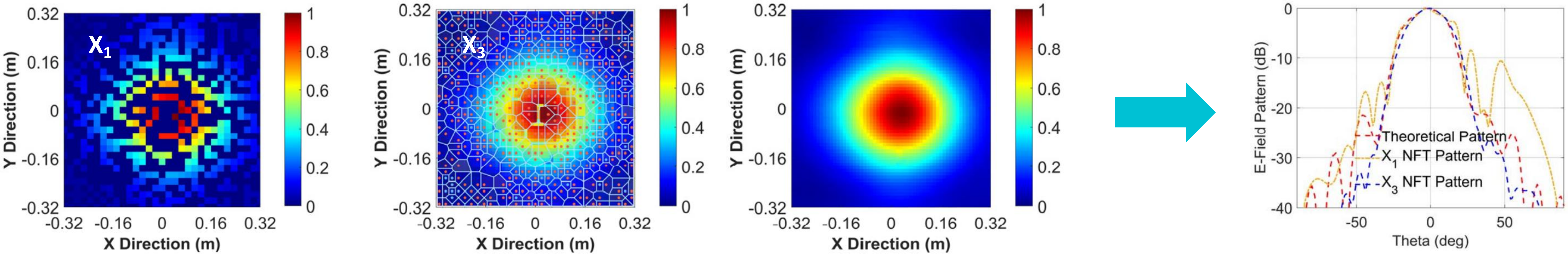
- **State of the art: Adaptive near-field scans ***


IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 71, 2022

An Effective Antenna Pattern Reconstruction Method for Planar Near-Field Measurement System

Junhao Zheng, Xiaoming Chen, *Senior Member, IEEE*, and Yi Huang, *Fellow, IEEE*

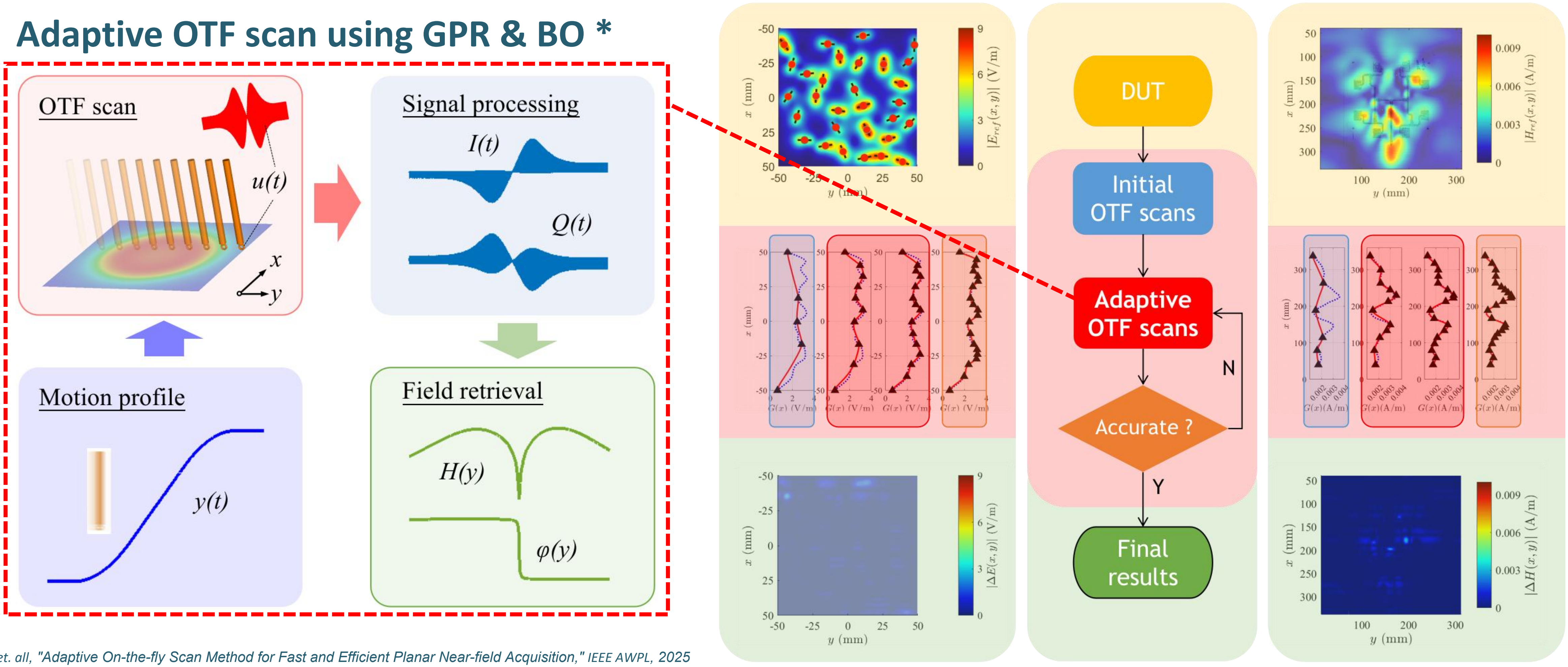




* *J. Zheng et al.,"An Effective Antenna Pattern Reconstruction Method for Planar Near-Field Measurement System," 2022, doi: 10.1109/TIM.2022.3193194.*

II. Methodology

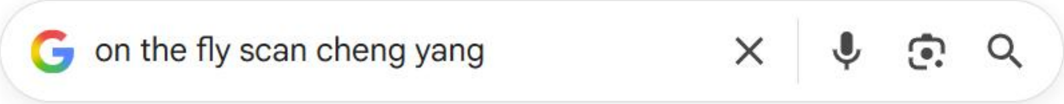
- **Adaptive OTF scan using GPR & BO ***

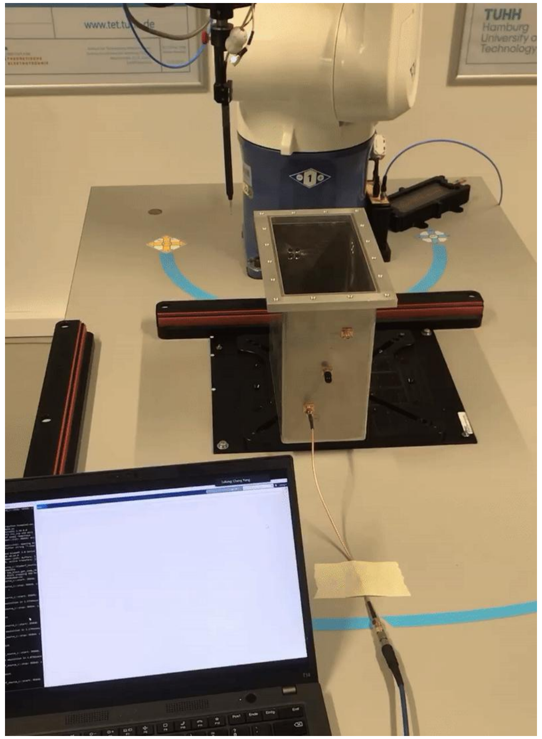


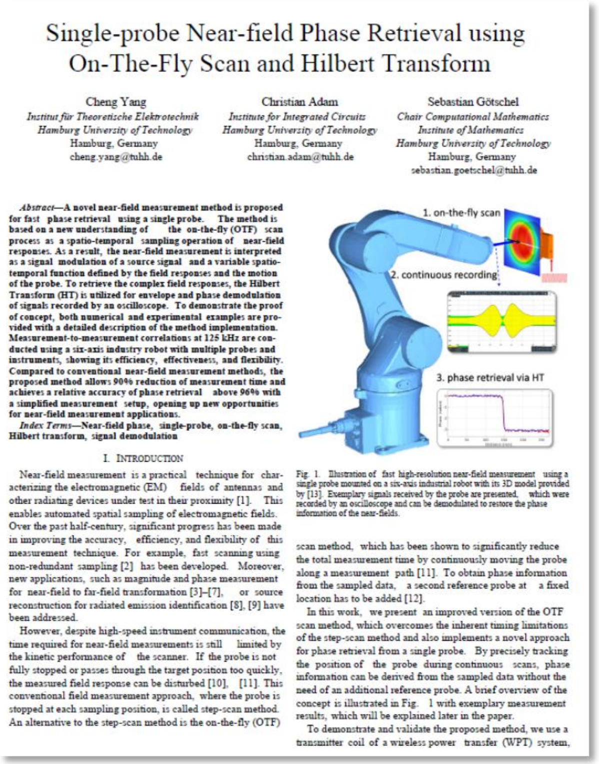
* C. Yang, et. all, "Adaptive On-the-fly Scan Method for Fast and Efficient Planar Near-field Acquisition," IEEE AWPL, 2025

II. Methodology

- **OTF scan ***







Single-probe Near-field Phase Retrieval using On-The-Fly Scan and Hilbert Transform

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Abstract—**A novel near-field measurement method is proposed for fast phase retrieval using a single probe. The method is based on a new understanding of the on-the-fly (OTF) scan process as a spatio-temporal sampling operation of near-field responses. As a result, the near-field measurement is interpreted as a signal modulation of a source signal and a variable spatio-temporal function defined by the field responses and the motion of the probe. To retrieve the complex field responses, the Hilbert Transform (HT) is utilized for envelope and phase demodulation of signals recorded by an oscilloscope. To demonstrate the proof of concept, both numerical and experimental examples are provided with a detailed description of the method implementation. Measurement-to-measurement correlations at 125 kHz are conducted using a six-axis industry robot with multiple probes and instruments, showing its efficiency, effectiveness, and flexibility. Compared to conventional near-field measurement methods, the proposed method allows 90% reduction of measurement time and achieves a relative accuracy of phase retrieval above 96% with a simplified measurement setup, opening up new opportunities for near-field measurement applications.**

Index Terms—**Near-field phase, single-probe, on-the-fly scan, Hilbert transform, signal demodulation**

I. INTRODUCTION

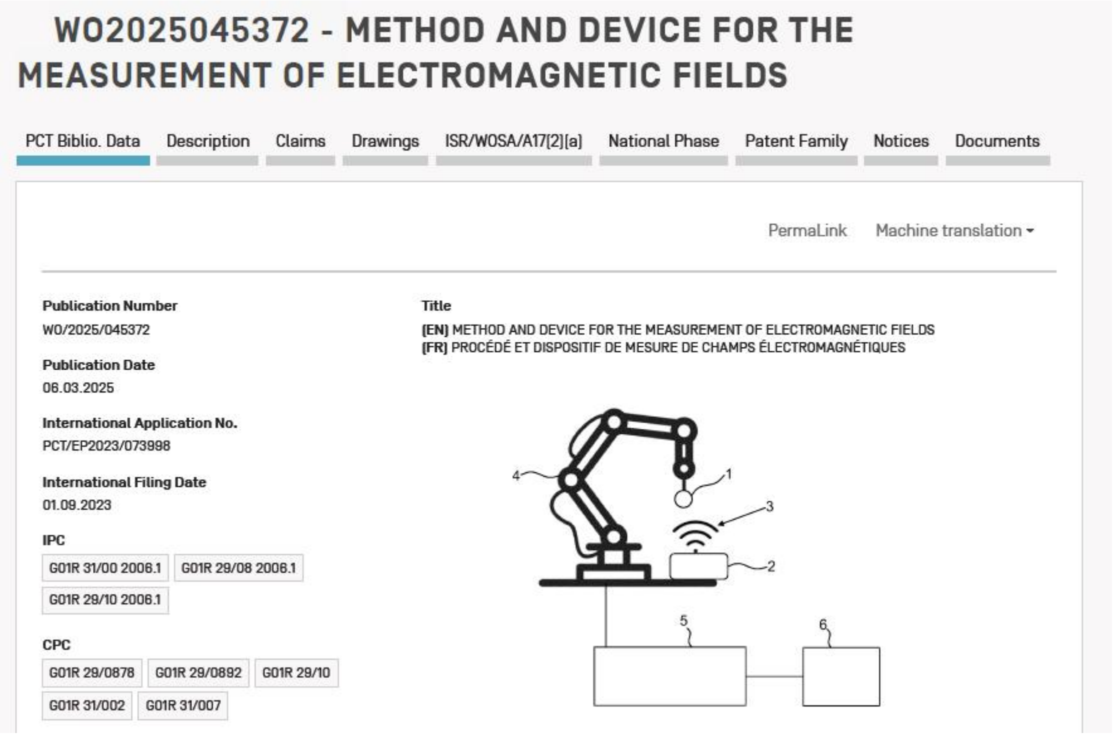
Near-field measurement is a practical technique for characterizing the electromagnetic (EM) fields of antennas and other radiating devices under test in their proximity [1]. This enables automated spatial sampling of electromagnetic fields. Over the past half-century, significant progress has been made in improving the accuracy, efficiency, and flexibility of this measurement technique. For example, fast scanning using non-redundant sampling [2] has been developed. Moreover, new applications, such as magnitude and phase measurement for near-field to far-field transformation [3]–[7], or source reconstruction for radiated emission identification [8], [9] have been addressed.

However, despite high-speed instrument communication, the time required for near-field measurements is still limited by the kinetic performance of the scanner. If the probe is not fully stopped or passes through the target position too quickly, the measured field response can be disturbed [10], [11]. This conventional field measurement approach, where the probe is stopped at each sampling position, is called step-scan method. An alternative to the step-scan method is the on-the-fly (OTF) scan method, which has been shown to significantly reduce the total measurement time by continuously moving the probe along a measurement path [11]. To obtain phase information from the sampled data, a second reference probe at a fixed location has to be added [12].

In this work, we present an improved version of the OTF scan method, which overcomes the inherent timing limitations of the step-scan method and also implements a novel approach for phase retrieval from a single probe. By precisely tracking the position of the probe during continuous scans, phase information can be derived from the sampled data without the need of an additional reference probe. A brief overview of the concept is illustrated in Fig. 1 with exemplary measurement results, which will be explained later in the paper.

To demonstrate and validate the proposed method, we use a transmitter coil of a wireless power transfer (WPT) system,

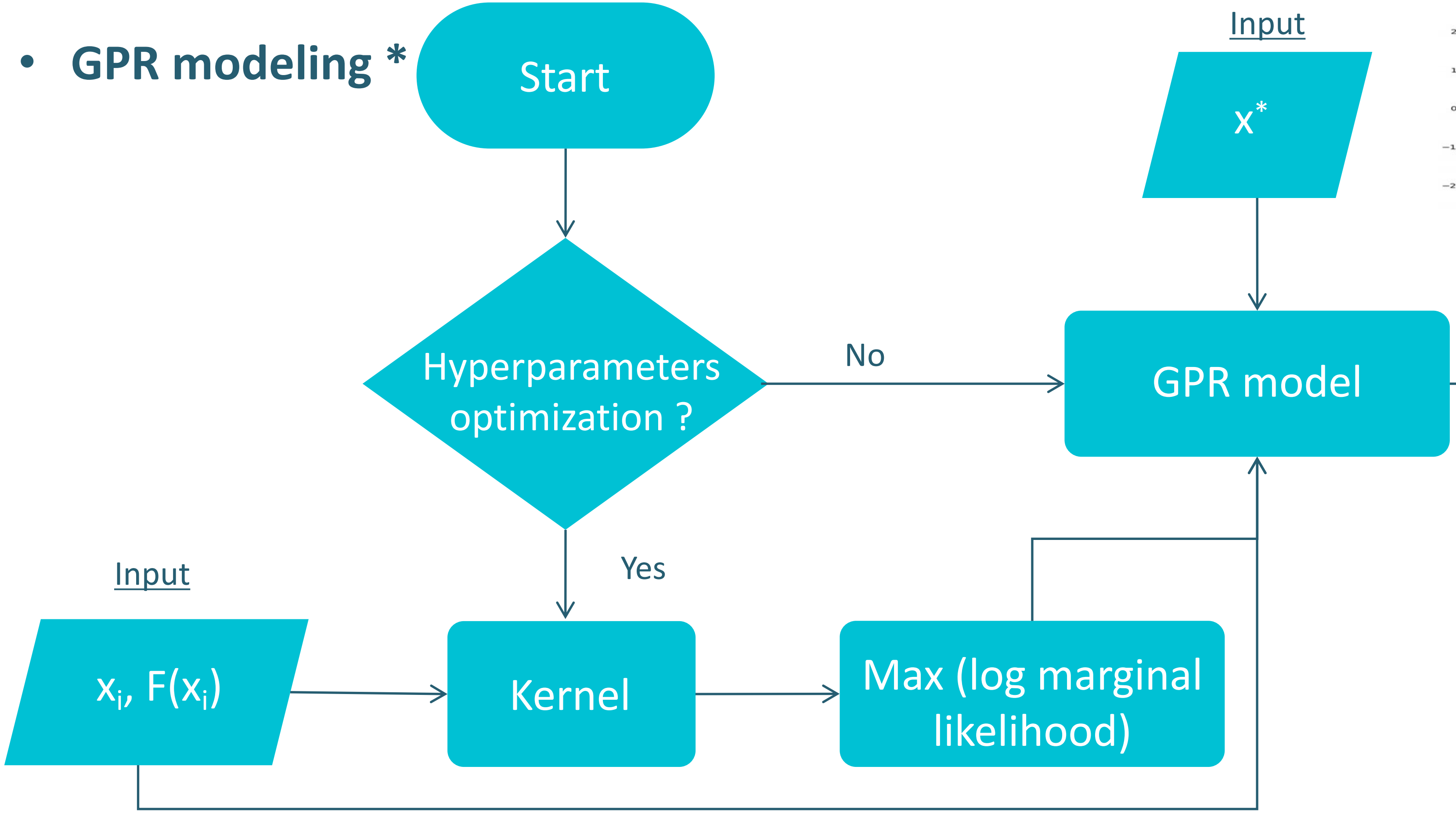
Fig. 1. Illustration of fast high-resolution near-field measurement using a single probe mounted on a six-axis industrial robot with its 3D model provided by [13]. Exemplary signals received by the probe are presented, which were recorded by an oscilloscope and can be demodulated to restore the phase information of the near-fields.

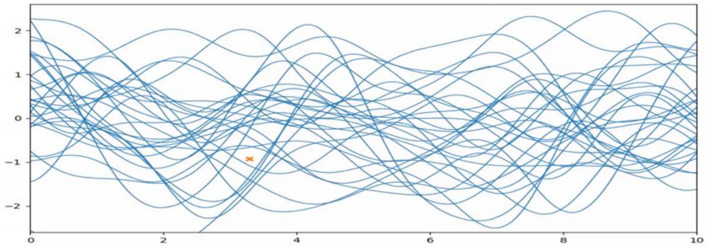


* C. Yang, C. Adam, S. Götschel, "Single-probe Near-field Phase Retrieval using On-The-Fly Scan and Hilbert Transform", EMC Europe 2023, Krakow, Poland, Sep. , 2023.
C. Yang, C. Adam, S. Götschel, WO2025045372 - METHOD AND DEVICE FOR THE MEASUREMENT OF ELECTROMAGNETIC FIELDS, patent, 2023

II. Methodology

- **GPR modeling ***

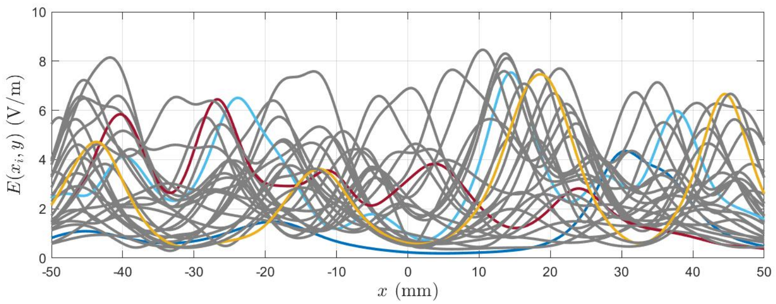


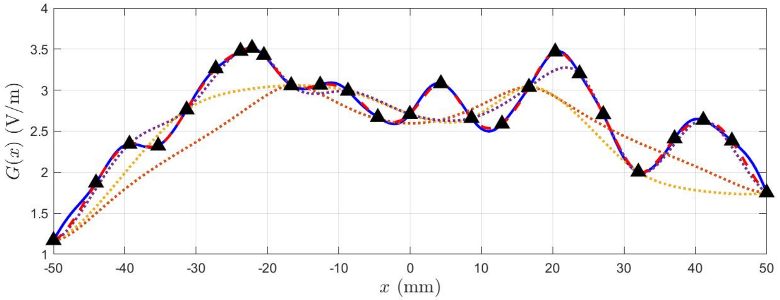


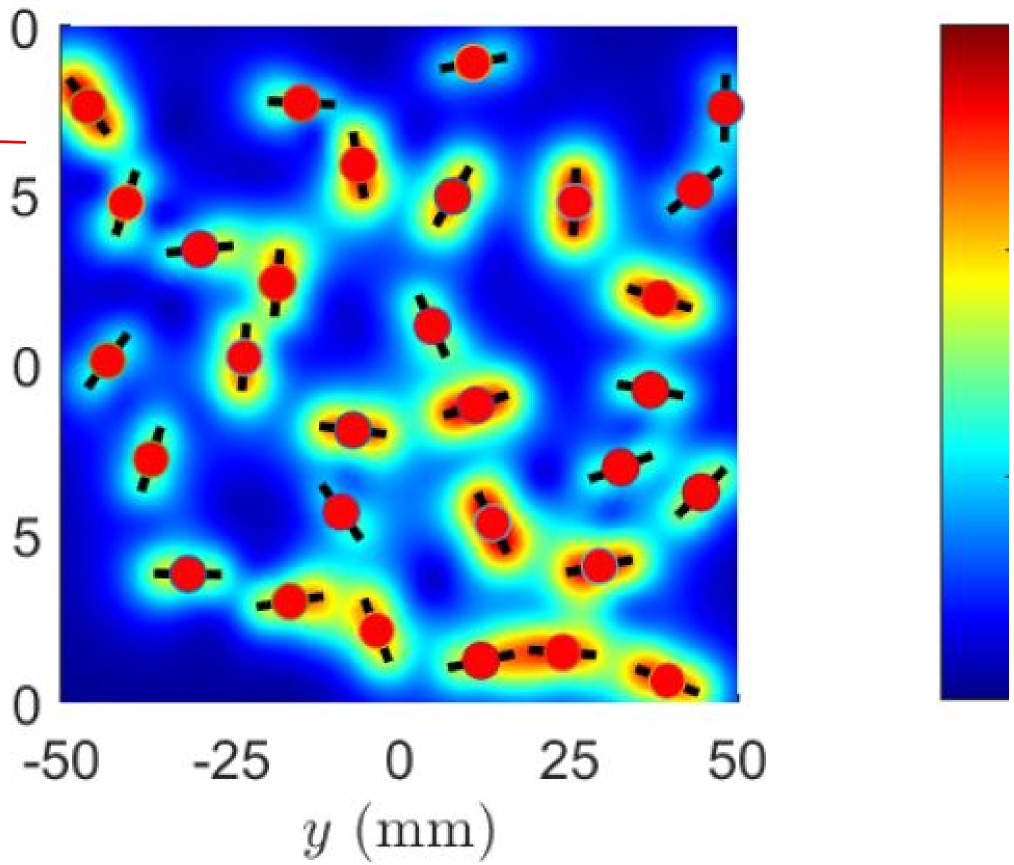
II. Methodology

- **Core idea: 2D surface scan -> 1D line scan**

$$G(x) = \frac{1}{y_b - y_a} \int_{y_a}^{y_b} F(x, y')\, dy'$$

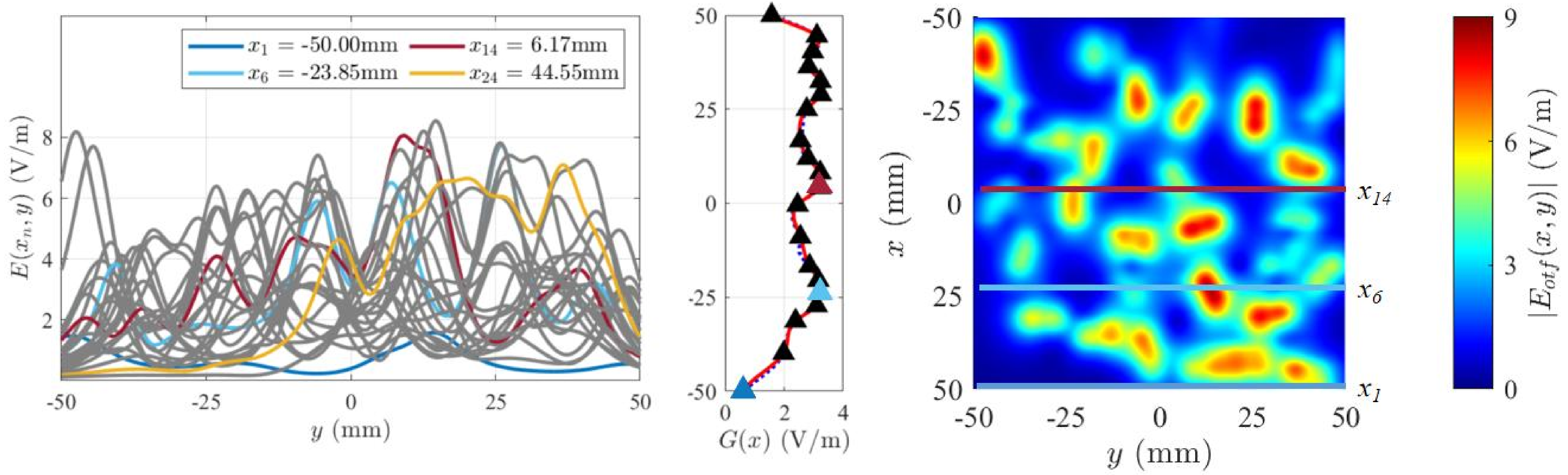






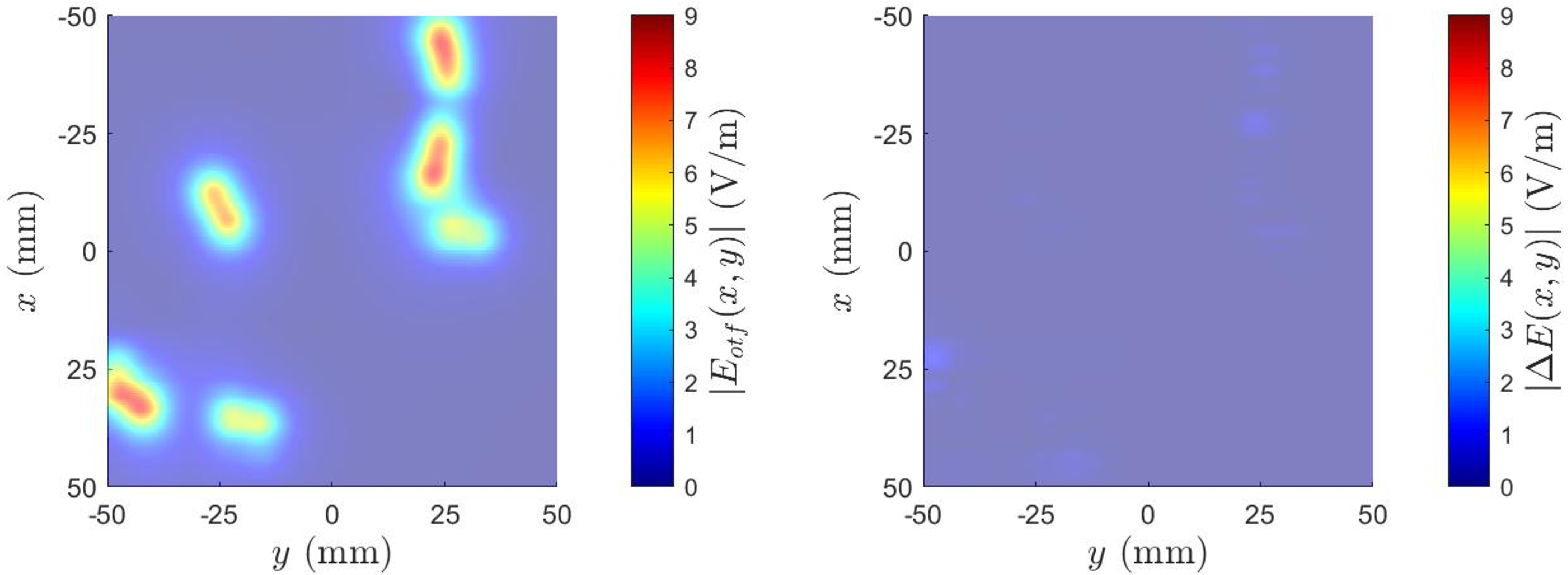
II. Methodology

- **Core idea: 2D surface scan -> 1D line scan**



II. Methodology

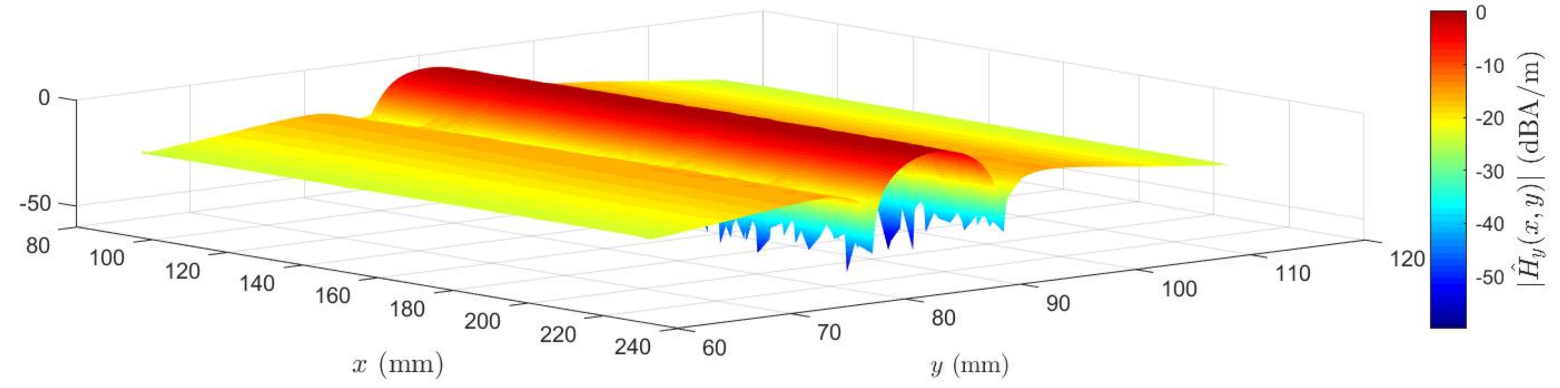
- **Numerical validations using a dipole array**

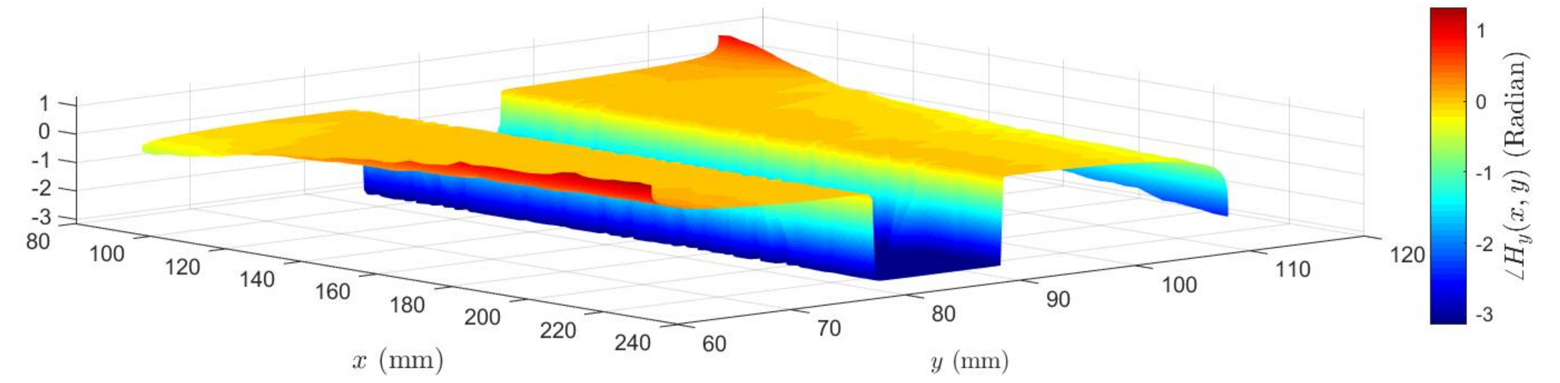


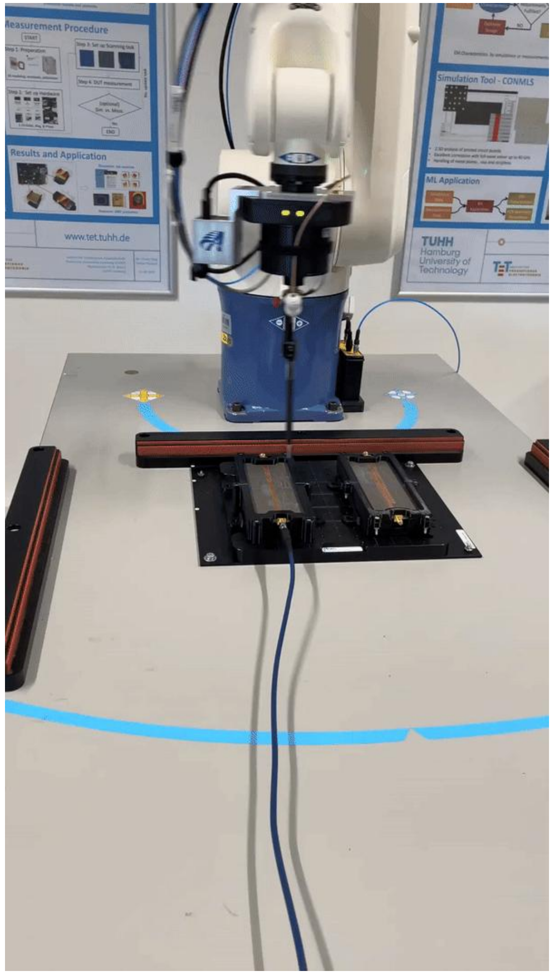
Content

III. Implementation

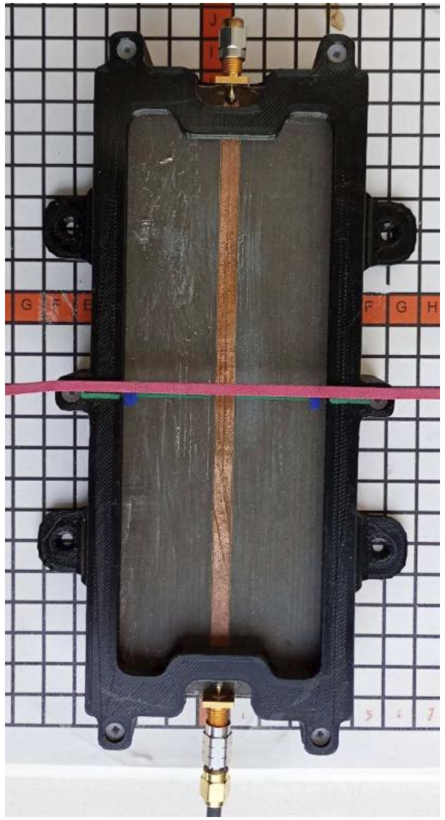
- **OTF scan test using industry robot**

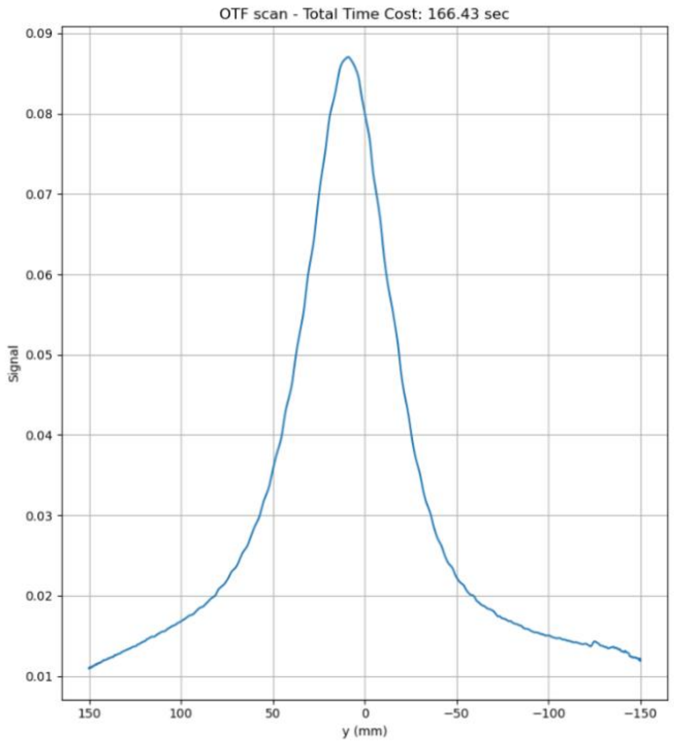


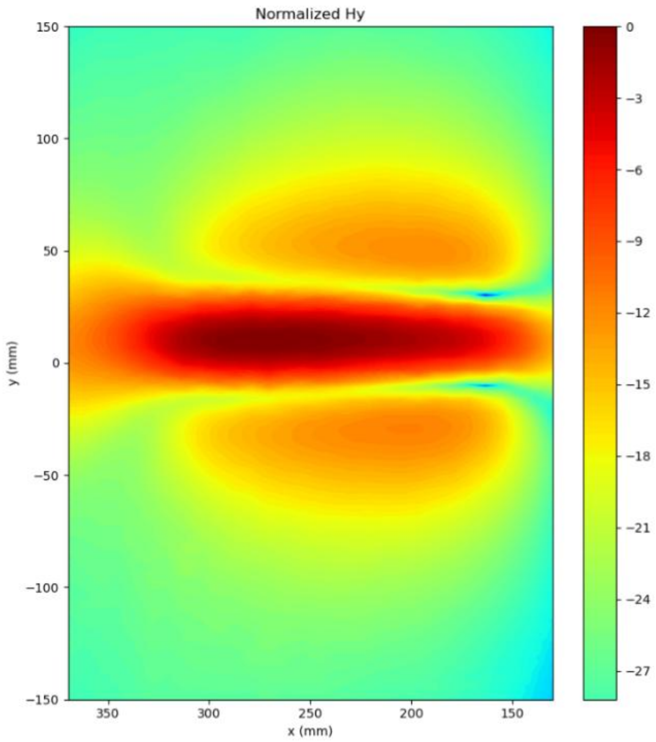




- **Performance testing: transmission line**

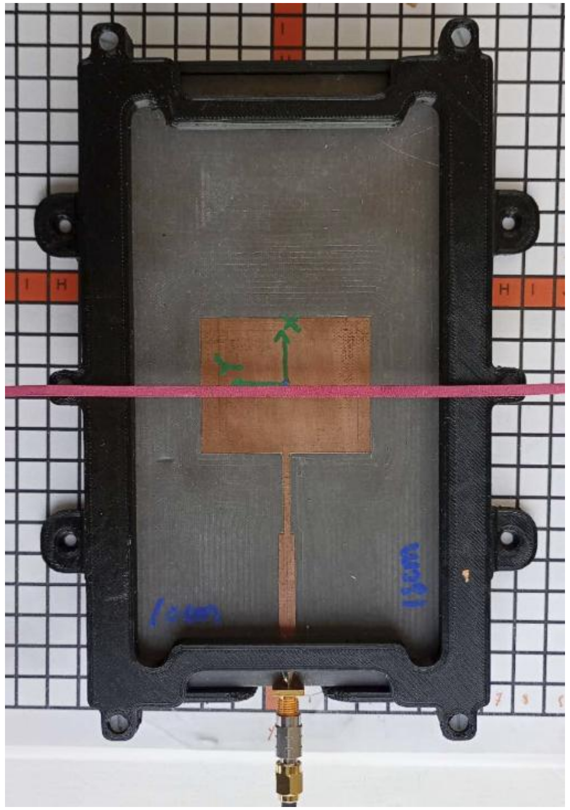


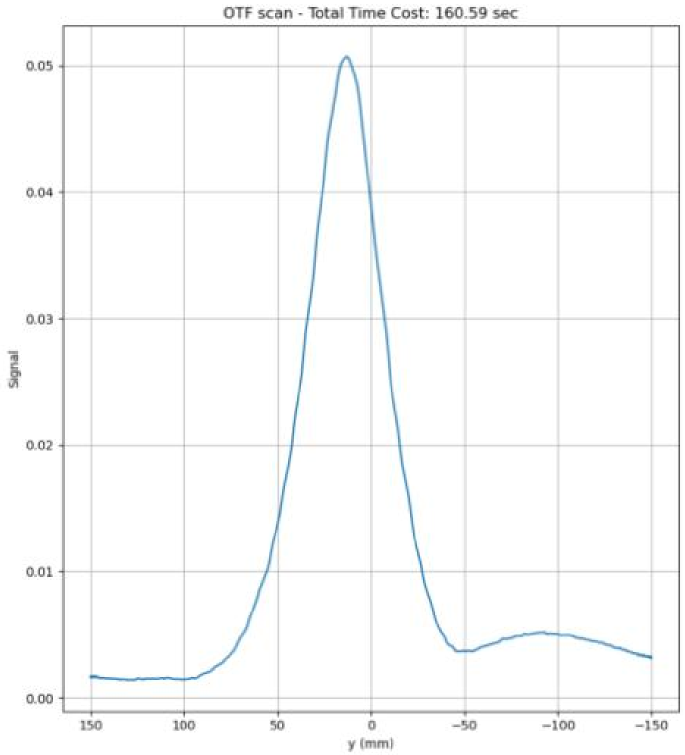


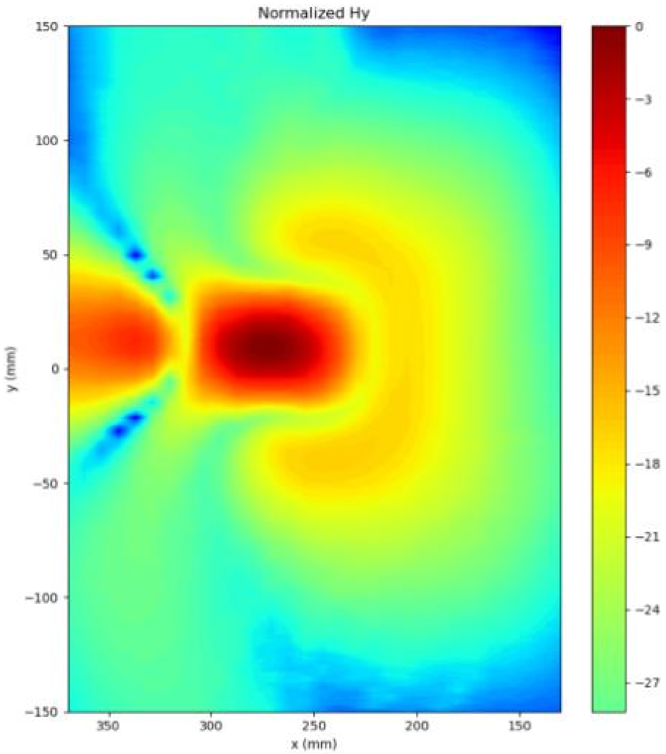


Example 1 - microstrip line (@ 1GHz)

- **Performance testing: single antenna**

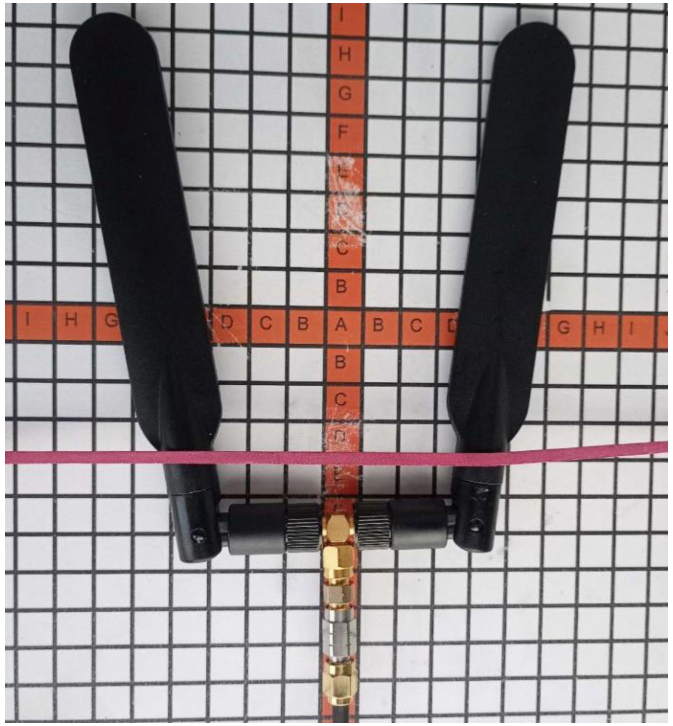


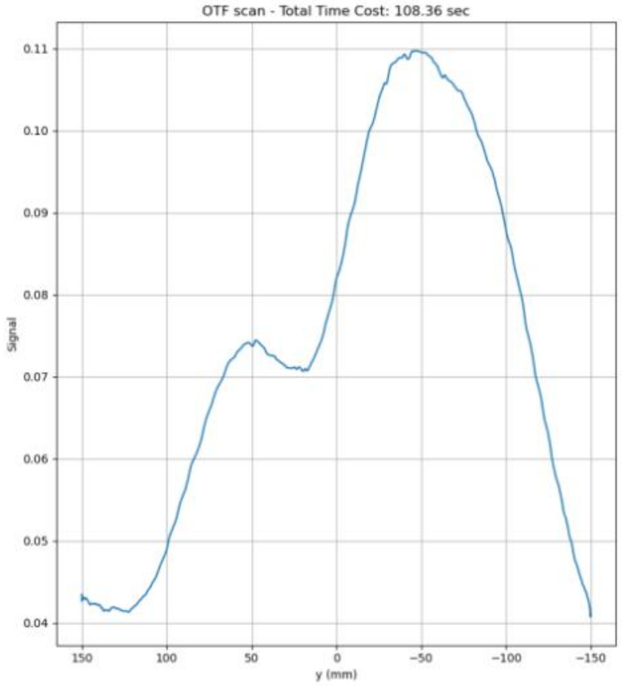


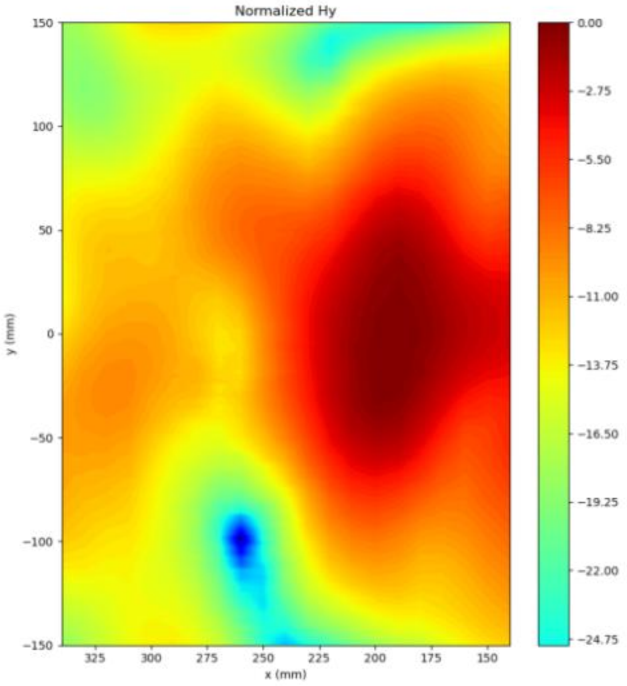


Example 2 - patch antenna (1.0 GHz)

- **Performance testing: a pair of WiFi antenna**







2D field scan - a pair of WiFi antennas (2.4 GHz, case 3)

III. Implementation

- **Adaptive OTF scan using ML**

This article has been accepted for publication in IEEE Antennas and Wireless Propagation Letters. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/LAWP.2025.3557192

Adaptive On-the-fly Scan Method for Fast and Efficient Planar Near-field Acquisition

Cheng Yang, *Senior Member, IEEE,* Tomas Monopoli, Sebastian Götschel, Xinglong Wu, *Senior Member, IEEE,* Flavia Grassi, *Senior Member, IEEE,* and Christian Schuster, *Fellow, IEEE*

Abstract—**Recent advancements in adaptive planar near-field scanning have enhanced the use of sparse measurement data for electromagnetic field (EMF) modeling and prediction. In this work, we propose an adaptive planar scanning solution that utilizes iterative row-by-row scans, where each row is scanned on-the-fly (OTF). Both the total number of rows and their separation are dynamically adjusted and optimized through correlation analysis of the values obtained from previous measurements. For initialization, a few evenly distributed row scans, typically 4-6 OTF scans, are performed, followed by an iterative process of finding new rows to scan using Gaussian Process Regression (GPR) based Bayesian optimization. For validation, both numerical and experimental examples, including wire and patch antenna arrays, are provided. Results show good performance of the proposed method, enabling rapid near-field acquisition within minutes, making it suitable for large-scale and high-resolution EMF scanning applications.**

Index Terms—**Near-field measurement, adaptive sampling, on-the-fly scan, Bayesian optimization, Gaussian Process.**

I. Introduction

RADIO frequency near-field scan (NFS) measurement is a sophisticated technique with wide-ranging applications, such as integrated circuits, antenna measurements, and electromagnetic compatibility (EMC) tests [1], [2]. Due to variations of field distribution at sub-wavelength scale, near-field scanning generally requires much higher spatial resolution compared to far-field measurements. Depending on the field probe in-use and the performance of the positioning system, the best spatial resolution achievable in near-field scanning typically begins at several tens of micrometers. Hence, when performing an equidistant near-field scan with sub-millimeter spatial resolution, even a scan area of just a few centimeters can require significant time and effort.

Over the past decade, researchers and engineers have made extensive efforts to provide effective solutions, reducing both the required sampling points and the average measurement time per point. For example, the total number of points required for NFS, can been minimized through adaptive field acquisition using sparse sampling techniques. These include iterative sampling using interpolation technique [3]–[5], machine learning (ML) method [6], [7], and sequential spatial adaptive sampling [8], [9]. These approaches have shown successful applications in benchmark examples with experiments. Meanwhile, high-bandwidth instruments and high-speed scanning gantries have been integrated in modern NFS systems, greatly reducing measurement times and waiting periods. This enables NFS in motion, known as on-the-fly (OTF) scanning, drift scanning, or raster scanning [10], as an alternative method to minimize scanning time.

Recently, the OTF method has been further enhanced based on a new reformulation of the problem from a signal processing perspective [11]–[13], eliminating overall communication overhead during the measurement which will be briefly described in Sec. II. Building on this new OTF scan technique, we propose a novel adaptive scanning method for planar NFS that utilizes iterative OTF scans rather than traditional point-wise scans. The remainder of this paper will first explain the details of this approach, followed by numerical and experimental validations, and final a conclusion.

II. Adaptive OTF Scan Approach

As shown in Fig. 1, the OTF scan begins with a predefined motion profile, $y(t)$, which specifies the full scanning time and velocity. During the scan, the transient probe signal is fully captured as $u(t)$. Theoretic derivation discloses that the motion effects on the induced probe signal corresponds to a magnitude- and phase-modulation. Through in-phase and quadrature (IQ) demodulation followed by time-to-space mapping, the spatial complex field distribution, $H(y)$ and $\phi(y)$, can be precisely reconstructed from $u(t)$ and $y(t)$. Notably, the enhanced OTF scan differs from the standard OTF scan in its continuous data acquisition and post-processing. A detailed formulation and explanation can be found in [11], [13]. In the following, the enhanced OTF scan method is to be applied to adaptive planar near-field scans.

In a planar near-field measurement, the traditional adaptive scan approach treats sampling as a 2D problem, using a step-scan method that captures the field point-by-point. By substituting a point-by-point scan with a line-by-line scan, we propose an adaptive OTF scan method. In this approach, iterative line scans are performed along the y-axis, from (x, y_a) to (x, y_b) at fixed x-coordinates, referred to as row

Manuscript received **, 2025; (Corresponding author: Cheng Yang.)

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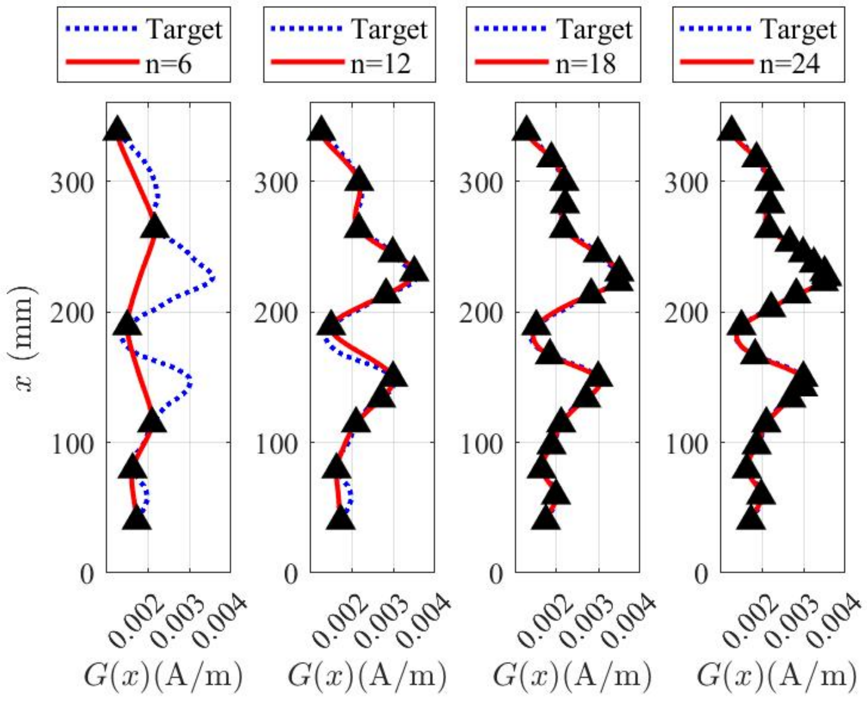

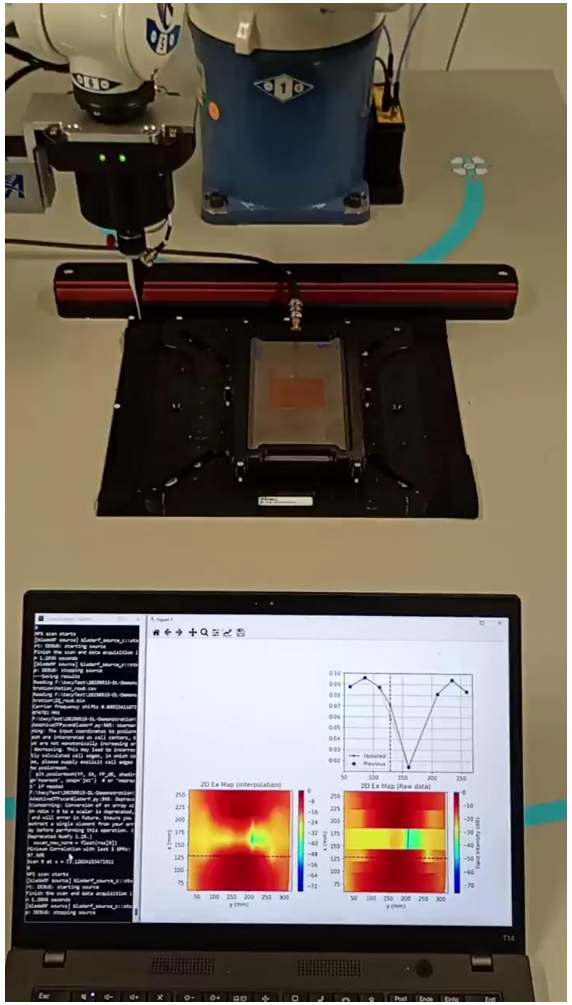

* C. Yang, et. all, "Adaptive On-the-fly Scan Method for Fast and Efficient Planar Near-field Acquisition," *IEEE AWPL*, 2025

Content

IV. Summary

TUHH

With the proposed OTF scan solution, we could:

- Perform **rapid scans** with high spatial resolution (time)
- Conduct efficient **large-area scans** (size)
- Develop a **portable** and **cost-effective** scanner (price)
- Carry out flexible **on-site EMC diagnostics** (ability)
- Validate EMC countermeasures efficiently (potential)

Thank you

for your attention

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