Using Deep Neural Networks for Disambiguation of Magnetic Microwire Responses

DS01 Symposium — MRS 2022 Spring Meeting

Akshar Varma[*, 1], X. Zhang[2], B. Lejeune[2], L. C. Almagro[4], R. P. del Real[5, 6], M. P. M. Palacios[4, 6], O. Fitchorova[2,8], L. H. Lewis[2, 8] and R. Sundaram[1]

[*]varma.ak@northeastern.edu [1]Khoury College of Computer Sciences, Northeastern University, USA [2]College of Engineering, Northeastern University, USA [4]Department of Physics, Complutense University of Madrid, Spain [5]Instituto de Ciencia de Materiales de Madrid (ICMM), Spain [6]Instituto de Magnetismo Aplicado (UCM), Unidad Asociada (CSIC), Spain [8]The George J. Kostas Research Institute for Homeland Security, Northeastern University, USA

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Motivation

Counterfeit Medicinal Supply Chains

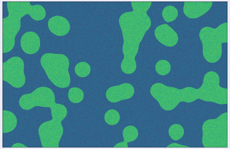
$870 Billion
Worldwide annual sale of counterfeit drugs and medical products

90%
Increase in counterfeit medicine over 5 years

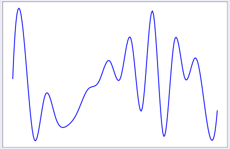
>500,000
Annual death toll caused by counterfeit drugs

Proposal: Remote Tagging Systems

Tag: a physical arrangement of special material ←···· Create a Tagging System? ····→ Response: the measured physical property



Measure →



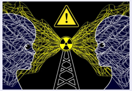
This requires disambiguating configurations of materials given their measured properties.

Why not existing technologies?

Authentication systems $\longleftrightarrow$ plethora of desirable properties $\not\longleftrightarrow$ current technologies.

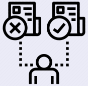
Undesirable properties

Line of Sight 

Radiation 

Range limits 

Difficulty in integration 

Forging/Tampering 

Actively powered 

Magnetic Microwires (MWs) and their useful properties

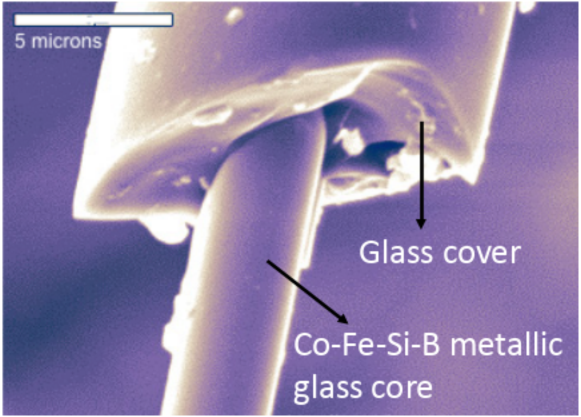


Figure: SEM micrograph of glass-coated microwire.[a]

Unique core-shell composite structure

- Core: soft magnetic (CoFe)SiB amorphous alloy
- Shell: pyrex glass cover $\Longrightarrow$ Bio-compatibile
- Diameter $\sim$5–60 microns

Promising functional response properties

- Ultra-soft ferromagnetism
- Unique magnetism-stress correlation
- Electromagnetic interactions

[a] Vázquez, M. (2007). Advanced Magnetic Microwires, Handbook of Magnetism and Advanced Magnetic Materials, J. Wiley Vol. 4, 2192-2222

MWs have sensitive S_{21} response in 1–5 GHz range

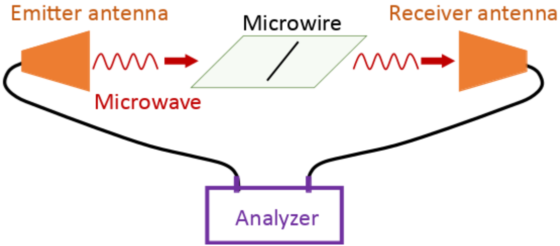


Figure: Schematic of experimental apparatus to measure the S_{21} response of arrays of MWs.

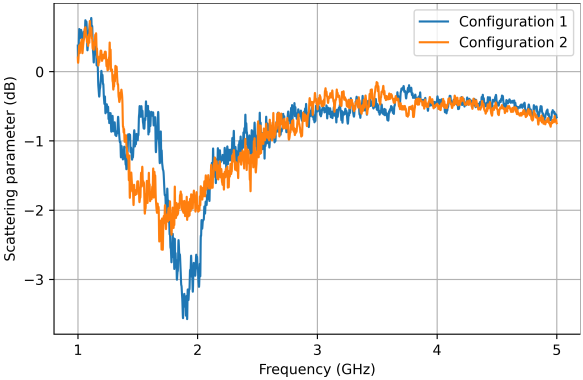


Figure: The configurations are two parallel 4 cm wires with different separations between them.

- **Tag/Configuration**: the physical arrangement of the MWs on the measurement platform.
- **S_{21} Response**: the microwave radiation absorption profile exhibited by a configuration.

The Problem

Problem statement

Given a measurement function, generate *many* tags such that the corresponding responses can be disambiguated.

Difficulties

- The measurement function is:
  1. defined by nature (we have no control it);
  2. is complex (has no closed form equation).
- These two factors eliminate the use of most classical tools from computer science.

Solution (rest of the talk)

- We'll present our deep neural network model to solve this problem.
- Technical details for simulating the measurement function, a key part of our model.

Dispersive Autoassociative Neural Networks (DANN)

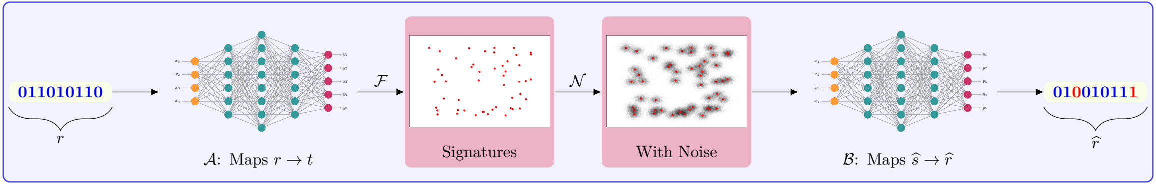
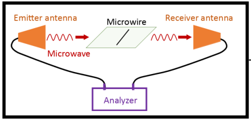


Figure: The **D**ispersive **A**utoassociative **N**eural **N**etwork architecture.

This needs the ability to simulate the measurement function, our focus for the rest of the talk.

Simulating the measurement function



Collect

Data

300 (microwire configuration, signature) pairs

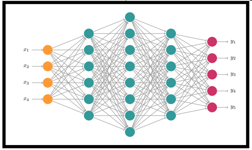
90% for training

10% for testing

Match predictions
to true signature.

Predict on unseen data

Deep Neural Network

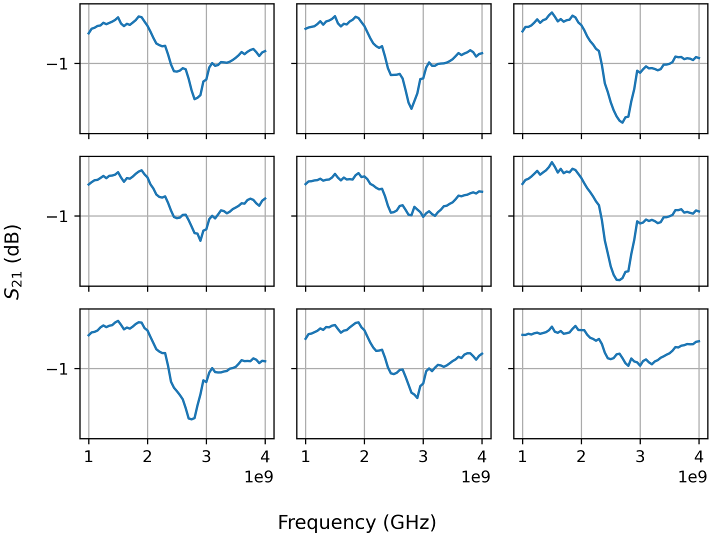


Testing with trained model

Training error	Test error
0.06 ± 0.005	0.08 ± 0.007

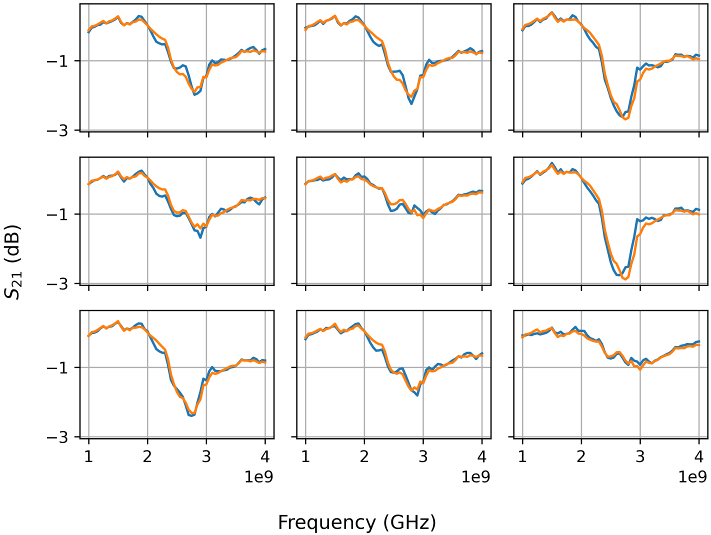
Testing: Plot of actual responses

Figure: Actual Response (blue) for various unseen tag configurations



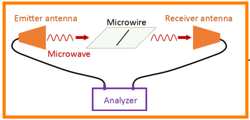
Testing: Plot of actual responses vs. our predictions

Figure: Actual Response (blue) and Predicted Response (orange) for various unseen tag configurations



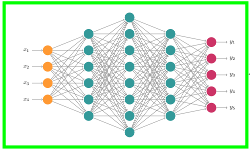
Handling different environments

New environment



Collect Data → New (microwire configuration, signature) dataset

Neural Network trained on original environment

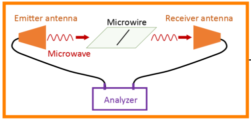


Testing on unseen dataset

Original test error	New test error
0.06 ± 0.007	0.18 ± 0.08

Handling different environments using fine tuning

New environment



Collect Data

New (microwire configuration, signature) dataset

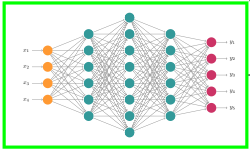
30–50 pairs

A few pairs set aside for fine-tuning.

Testing on everything else

Neural Network trained on original environment

Fine-tuning the network



Testing on rest

Original test error	New test error	New test error (+fine-tuning)
0.06 ± 0.007	0.18 ± 0.08	0.09 ± 0.008

Takeaways and next steps

Takeaways

- We are able to simulate the measurement function for magnetic microwires.
- Our model can adapt to changes in environment.
- Preliminary results: DANN gets 10-100x configurations compared to naive approaches.

Next steps

- Ongoing: DANN $\longrightarrow$ generate a large set of MW tags.
- Open: Use other materials like DNA, fluorescent dyes, opto-chemical inks, etc.
- Open: Design a combination of materials that gives the best disambiguation ability.

Use the QR code to visit our group's website:
`https://disrpt.sites.northeastern.edu`

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