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AI's potential for Artificial Phantom Mimicking Tissue of the Human Breast Electrical Properties

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Abstract

In this study, we present an assessment method of Early Breast Cancer Detection based on Artificial Intelligence (AI). This method includes prediction, setting and measurement of several human breast phantom mixtures for Microwave Imaging (MWI). These developed Breast Phantoms have realistic dielectric properties (important for Radar Microwave Imaging Systems & Ethical Non-Animal-Testing). We Developed Heterogeneous mimicking tissue architecture for mimicking Breast Tissues (Fat, Regular Fat, Gland, Body Fluid, Blood, Muscle-Tumor, Skin Dry, and Skin Wet) and tested using ultrawideband frequency (0.2 GHz – 4.5 GHz) by a modern Vector Network Analyzer. Our qualitative and quantitative research includes the methodology and results for using the material's dielectric parameters and AI algorithms for emulation of real Breast Tissues for Microwave Imaging Pre-clinical trials.

Keywords

Artificial-Intelligence, Breast-Cancer, Breast-Phantoms, Microwave measurement, Microwave Imaging, Radar Imaging.

1. INTRODUCTION

Today newer Breast Cancer Diagnostic systems, less expensive, more comfortable, non-ionizing with same or better efficiency are developed. Microwave Imaging (MWI) is reported as one of the best, with accuracy around 80 – 90 % compared to other systems like X-ray mammography with 70.2%, MRI with 72.9%, Ultrasound with 67.8% and Breast Clinical examinations with 63.6% of accuracy to detect malignant Tumors [1], [2].

To make pre-clinical trials of these MWI device systems, our team developed Breast Phantoms with the help of AI. The used AI tools include Machine learning (ML) and Deep Learning (DL) algorithms in non-linear regression problems that involve multi-prediction. Our research work shows that using kitchen cost-effective ingredients and AI (Artificial Neuronal Networks: ANN), is possible to match the real breast tissue dielectric properties with high precision up to 1.71 of mean absolute error (MSE) and 5.69% of mean absolute percentage error (MAPE) as seen in (Fig. 2).

2. STATE-OF-THE-ART

In the literature, Breast Phantoms mimicking tissues for this kind of systems had been fabricated with complex laboratory chemicals without a successful complete matching all the Breast Tissues (with both Dielectric Constant and Conductivity properties for Radar Microwave Systems along a complete Ultra-Wide-Band (UWB) frequency range) [3].

1.1 AI for Breast Phantom Development

To our knowledge, there are no studies reported about Breast Phantom developments using AI's ANN or other DL techniques. This confirms a new field with big opportunities to push the development of a new generation of mimicking tissues Phantoms for several testing and validation proposes in the medical or industrial field, with parameters & conditions closer to reality.

1.2 Electromagnetic Properties of Breast Phantom

These Artificial breast phantoms can provide the following important Electrical Properties that interact with the Electromagnetic Waves.

- Relative Permittivity or Dielectric constant (ϵ_r)
- Dielectric Loss (ϵ_r'')
- Loss Tangent (δ) [Formula: $\delta = \epsilon_r''/\epsilon_r'$]
- Conductivity ($\sigma(\omega)$) [Formula: $\sigma(\omega) = \epsilon_r'' \times (2\pi\omega) \times \epsilon_0$]

However, for this case of MWI radar principle (detection of only scattering microwave signals), the only interesting properties for our phantoms to match are 2 of these 4 parameters, ϵ_r and $\sigma(\omega)$. This is related to the energy that travels across the bulk behaving differently according to the sample's conductivity (S/m), before it encounters another interphase.

Tissues	Dielectric Constant (ϵ_r)	Conductivity ($\sigma(\omega)$)
Skin Dry	~ 40.8	0.90 S/m
Skin Wet	~ 45.6	0.89 S/m
Muscle & Tumor	~ 54.76	0.98 S/m
Blood	~ 61	1.59 S/m
Fat	~ 5.4	0.05 S/m
Breast Fat	~ 5.4	0.05 S/m

Body Fluid	~ 69	1.67 S/m
Gland	~ 59.4	1.08 S/m

Table 1 - Real dielectric properties of tissues at 1GHz.

2 MATERIALS & METHODS

2.1 AI Predictions & Materials

To make our predictions we used MATLAB software with Deep learning Toolbox for the use of Artificial Neuronal Networks (ANN). For training, we used datasets of different dielectric properties from (0.2 – 4.5 GHz) corresponding to ingredients combinations (**Corn Flour**, **Water**, **Salt**, and **Sunflower Oil**) using the respective quantities in grams.

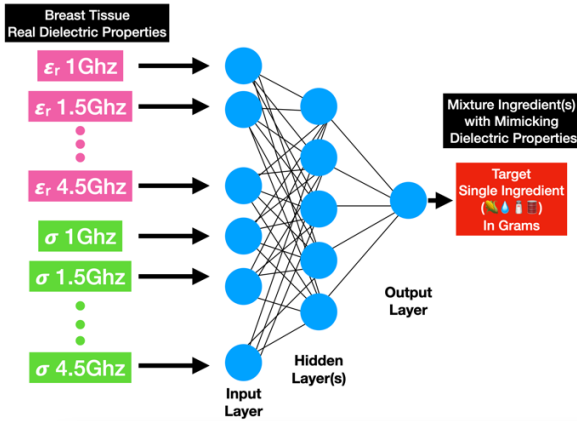


Figure 1 - ANN structure for Breast Phantom Ingredient Mixture Prediction

Pre-training treatment was defined by average data for multiple measures of the same mixtures, Outlier removal and Split Dataset for 70% train, 15% validation, and 15% test. Also, we did Jittering for data amplification, because the data set was not too big (~ 66 observations), in comparison to the Degrees of Freedom (DOF) theory [4].

For training we used a custom-made script to automatically test different architectures of ANN (with **Levenberg-Marquardt backpropagation**, and **Bayesian Regularization** algorithms) keeping only one single Target at the time and selecting the best hyperparameters at the end. Comparisons were done in terms of performance MSE of the Test Set.

2.2 Dielectric Measurements for Validation

The predicted sample mixtures were constructed and then measured in UWB range (200 MHz – 4.5 GHz). A dielectric probe kit, with Keysight Materials Measurement Suite Software, and Vector Network Analyzer (VNA) were used to measure (dielectric parameters) and compare the original ANN predictions.

3 RESULTS & DISCUSSIONS

The graphs in (Fig. 2) show the Breast Phantom Mixture predictions done by our “AI_Algorithm”, using ANN with our aimed MSE.

The optimal number of neurons (in a single layer) found by our algorithm, confirmed that shallow ANN are good candidates for our multi-response non-linear problem. The MSE & Root mean square error (RMSE) performance indicators confirmed good prediction generality for unseen data (measured from our unseen test-Dataset).

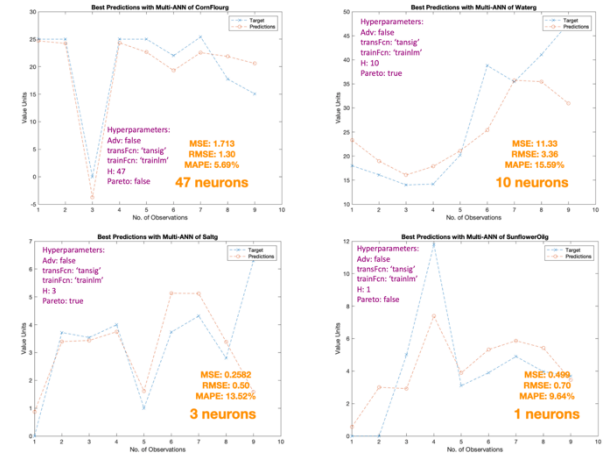


Figure 2 - Breast Phantom Mixture Predictions with Performance values

4 CONCLUSION

Our AI algorithms were validated for 88.89 % prediction accuracy (using MAPE) to predict the Phantom ingredients quantities for this non-linear Multi-response and Multi-frequency prediction problem (with very few data ~ 66 observations related to DOF theory). Results confirm that these breast phantoms are perfect candidates for a complex heterogeneous model for MWI system tests. The found RMSE ranges below 5 validated our data predictions, as they show a close scale to the one of our original datasets (in grams). In conclusion the results errors were close to ±1.3 grams for corn flour, ±3.36 grams for water, ±0.5 grams for salt and ±0.7 grams for sunflower oil.

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