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Interpolation of loudspeaker level balloons from polar measurements using U-net convolutional neural networks

**ABSTRACT**

Complete radiation balloons are needed to analyze the performance of loudspeakers and to perform accurate electroacoustic predictions of loudspeaker systems. A method is proposed to obtain full radiation balloons from horizontal and vertical polar measurements by using U-Net, a convolutional neural network architecture used for image processing.

# Introduction

Radiation patterns are fundamental in the design process of loudspeakers, both as targets and as real measurements to verify their performance. Electroacoustic simulation software based on loudspeaker models relies on radiation data to perform calculations of SPL and other acoustic parameters. These data should include complete radiation balloons in order to provide accurate results. A 5º resolution on Phi, Theta angles in spherical coordinates is proposed by the Loudspeaker polar radiation measurements AES standard to fully characterize a loudspeaker.

While the measurement of horizontal and vertical polars of a loudspeaker can be run with a single turntable in a relatively short time, the measurement of full radiation balloons requires complex acquisition devices to turn the loudspeaker or the microphones providing a large set of measurements on the surface of a sufficient distant sphere. The number of measurements and the time needed is significantly longer than for only horizontal-vertical polar measurements. Another alternative is the use of a near field scanners, which are not affordable for many companies or institutions, and also produces large datasets and are time consuming tasks.

This work presents a method to obtain complete SPL 3D balloons from horizontal and vertical measurements by using convolutional neural networks. While there are many papers describing the application of neural networks to predict full Head Related Transfer Functions from sparse measurements, these methods have not been applied to loudspeaker radiation prediction.

In the proposed method, radiation balloons are represented as images showing SPL in colours as function of frequency in the x axis and the different measurement points in the y axis as rows. Measurements with only polar data show only the response at vertical and horizontal polar points. This way, the problem has been reduced to an incomplete images recovery problem.

A dataset of images has been created from full balloon measurements. Input data images contain only the rows representing data at Phi= 0º, 90º, 180º, 270º (polar measurements), with any other rows set to zero. Output images contain all measurement points. An U-net has been trained with this data to predict filled images from incomplete ones.

With the proposed method a 4 dB mean absolute error (MAE) can be achieved on validation data (unseen by the NN during training process) for line array units (with strong differences between horizontal and vertical coverages, probably worst case). With more conventional loudspeakers the MAE is even better.

# Paper layout

[1] Gunnes

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The submission and final paper layout is a *one-sided, two-column* format with the font size of **10pt** and typeface **Times** or **Times New Roman**. The running header and footer appear on all pages except the first.



Figure 1. Figure caption.

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| Toyota | 1.00 | 0.83 | 0.87 | 0.48 |
| Honda | 0.83 | 1.00 | 0.73 | 0.18 |
| Ford | 0.87 | 0.73 | 1.00 | 0.16 |
| Mazda | 0.48 | 0.18 | 0.16 | 1.00 |

Table 1. ChevyNOVA analysis of multidimensionally-scaled data.

# Equations

Equations should be placed on separate lines and numbered. Also make sure that equations are readable in a printout.

 (1)

Where  is the calculated quantum interval

 (2)

It can be shown that

 (3)

where

 (4)

Applying theorem 3 to 1, the theory of phase transitions with differential nonlinearity can be expressed using Equation 5.

 (5)

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# Conclusions

This paper has described how better harmony has not only been achieved by bringing together many different types of bear in a musical context, but also how the outlined technology can be used to cross borders of species.

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