

**Ph.D. in Information Technology
Thesis Defense**

October 12th, 2026

At 11:00 a.m.

Seminar Room Alessandra Alario - Building 21

Giacomo Longo – 38th Cycle

MODELING AND OPTIMIZATION OF ACOUSTIC SYSTEMS USING NEURAL NETWORKS

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Abstract:

Acoustic systems are often characterized by structural complexity, multiphysical interactions, nonlinear behavior, and a strong dependence on construction parameters, driving signals, or both. These characteristics make it difficult to address their analysis, modeling, and optimization within a single methodological paradigm. This thesis investigates the role of neural networks as flexible tools for modeling, prediction, and compensation of such systems, with particular attention to their interaction with physics-based simulations, structured system representations, and experimental measurements. The work is organized around two complementary research directions. The first concerns the vibroacoustic analysis of an archtop guitar, adopted as a reference acoustic system whose behavior is strongly influenced by physical design variables. A parametrically defined finite-element model is developed to study the effect of selected geometric variations on modal behavior, bridge mobility, radiated sound pressure level, and radiation patterns. The resulting simulations provide a physically interpretable description of the relation between structural parameters and acoustic response. Neural networks are then trained as surrogate models to approximate the mapping from geometric, material, and damping parameters to selected vibroacoustic descriptors. Across the considered test outputs, the surrogate achieves a mean coefficient of determination of approximately $R^2 \simeq 0.93$ and reduces the evaluation time by orders of magnitude relative to the full multiphysics model, enabling rapid design-space exploration. The second research direction addresses the characterization, modeling, and compensation of a compact smartphone-based audio device employing piezoelectric transducers coupled to the display. In this context, the acoustic response is modified primarily through input-signal processing rather than through physical redesign. Experimental measurements are used to characterize the frequency- and level-dependent nonlinear behavior, harmonic distortion, and directivity of the device. Neural networks are then employed to model the measured input–output relationship and to develop inverse and linearizing strategies. The learned direct model is sufficiently accurate to serve as a differentiable proxy for inverse-model training, and the resulting preprocessing yields measurable reductions in distortion and improvements in spectral response, while remaining constrained by the model validity range, causality and delay, and the physical attainability of the selected target response. In parallel, circuit-based and Wave Digital formulations, including Biparametric Wave Digital Filters, are investigated as structured representations that support the integration and training of nonlinear components, including neural-

network-based ones, within physically meaningful models. These studies further show that the chosen representation domain can substantially affect the learnability of such components. Across these applications, neural networks are not treated solely as isolated black-box replacements for physical models. Instead, they are used as adaptable components within broader workflows: as surrogates of high-fidelity simulations, as approximators of nonlinear behavior, and as tools for inverse modeling and compensation. Taken together, the results show that the effectiveness of these models depends on their connection to physically interpretable parameters, structured representations, experimental data, and attainable processing targets. The thesis therefore contributes a methodology in which complex acoustic systems are made more analyzable and predictable, while design-space exploration and signal-processing optimization are supported without disregarding the constraints of the underlying physical devices.

PhD Committee

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