ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
ČESKÁ AKUSTICKÁ SPOLEČNOST

6. STUDENTSKÝ AKUSTICKÝ SEMINÁŘ

23. ledna 2025

Praha

Redakce sborníku: Petr Honzík, Václav Vencovský, František Rund

Sborník 6. studentského akustického semináře

Redakce sborníku: Ing. Petr Honzík, Ph.D.
Ing. Václav Vencovský, Ph.D.
Ing. František Rund, Ph.D.

URL: https://mmtg.fel.cvut.cz/student-acoustic-seminar/

Příspěvky otištěné ve sborníku nebyly redakčně upravovány.

ISBN 978-80-01-07401-5

Vydalo: České vysoké učení technické v Praze, 2025
Zpracovala: Fakulta elektrotechnická
Kontaktní adresa: Petr Honzík, Technická 2, 166 27 Praha 6
Tel. +420 22435 2240

20 stran
1. elektronické vydání

Obsah

Biografie prezentujících autorů

David Ringsmuth

David Ringsmuth was born in Prague, Czech Republic, in 1997. He received the B.S. degree in electrical engineering from Czech Technical University in Prague, Prague, in 2023, where he is currently pursuing the M.S. degree in electrical engineering with specialization in electronics. As a part of the SGS Project, he continues his research of a condenser microphone and develops an application for measuring characteristics of microphones.

David Hromas

David Hromas was born on December 5, 2000, in Prague. He graduated from Gymnasium Špitálská in 2020. He then pursued a degree in Audio Engineering, specialization audio production and recording, at the Faculty of Electrical Engineering and Communication (FEEC) at Brno University of Technology (BUT), earning his Bachelor's degree in 2023. Currently, he is studying Electronics and Communications, specialization audiovisual technology and signal processing, at the Faculty of Electrical Engineering (FEE) at Czech Technical University (CTU) in Prague.

Katerina Polakova

Katerina Polakova is a master's student at the Czech Technical University, specializing in Cybernetics and Robotics. Currently, she is conducting research on spontaneous otoacoustic emissions generated by a nonlinear cochlear model for her master's thesis. In addition to her studies, she is passionate about vehicle prototyping, with a focus on developing innovative solutions in the automotive industry.

Abhishek Singh

Abhishek Singh is an acoustician with experience and research interest in sound measurements, metamaterials, noise cancellation, and piezoelectricity. He is a graduate of the Indian Institute of Technology, Mandi, India and currently pursuing his doctorate at the Department of Physics, FEE, CTU in Prague.

Miroslava Kozlová

Born on February 2, 1992, in Jindřichův Hradec, she obtained her master's degree in Physical Measurement and Modelling in 2018 from the University of South Bohemia in České Budějovice. Subsequently, she joined the Robert

Bosch company as a test engineer and worked at the Competence Center for Noise, Vibration, and Harshness. Additionally, she is studying the doctoral program in Acoustics at the Czech Technical University in Prague via distance learning.

Jiří Bečka

Born in 1996 in Prague. He graduated from the Faculty of Civil Engineering at the Czech Technical University in Prague in 2022 (study programme Buildings and Environment). Currently he is pursuing PhD studies in Acoustics. His supervisor is prof. Ing. Ondřej Jiříček, CSc. (FEL), supervisor-specialist Ing. Jiří Nováček, Ph.D. (FSv). In his PhD thesis, he focuses on the use of renewable and recycled materials in soundproofing elements. He is partly employed at UCEEB CTU, where he is involved in sustainable construction. Besides school he is part of KONTRAHLUK, s.r.o. - a specialized company focusing on noise and acoustics.

Aneta Furmanová

Graduated from the Faculty of Electrical Engineering at the Czech Technical University in Prague (CTU, FEE) in 2023 with a Bachelor's Degree. In her bachelor's thesis, she focused on optimization of sound absorption in rectangular acoustic black holes. Currently a master's student at CTU, FEE, with research interest in numerical optimization and data-driven discovery in sound transmission in acoustics. During her internship at Graz University of Technology, she focused on implementation of Physics Informed Neural Networks for solving the Helmholtz equation.

ČESKÁ AKUSTICKÁ SPOLEČNOST

CZECH ACOUSTICAL SOCIETY

23. 1. 2025

Software for measuring characteristics of electroacoustic transducers

David Ringsmuth

Czech Technical University in Prague, Faculty of Electrical Engineering,
Technická 2, 160 00 Praha 6

`ringsdav@fel.cvut.cz`

1 INTRODUCTION

This project aims to develop a Matlab application for measuring characteristics of various electroacoustic transducers. Its goal is to expand the existing software for controlling a measuring apparatus [1], which was used for measuring polar characteristics of a specific microphone.

2 METHODS

The software uses a synchronized swept-sine signal [2] to measure the transducer's frequency response. The swept-sine is generated using the equation

$$x(t) = \sin\left(2\pi f_1 L e^{\frac{t}{L}}\right), \tag{1}$$

where $L = \frac{T}{\ln(f_2/f_1)}$, f_1 and f_2 is the frequency range and T is the signal duration.

A frequency response is calculated using the generated swept-sine and a recorded signal in multiple positions to display polar patterns of the measured microphone.

Higher harmonics frequency responses are used to estimate parameters of a non-linear system described by the Generalized Hammerstein model [2].

3 APPLICATION DESCRIPTION

The Matlab application controls the movement of a tested transducer attached to the measuring apparatus by communicating with an Arduino using a custom protocol. At each position, the frequency response is measured and the results are plotted as a frequency response at a specified position, polar plot at a specified frequency or a 3D plot.

Several parameters can be configured before measuring, including the swept-sine parameters, motor movement speed and direction and sound card options, such as input channels or the usage of a reference channel.

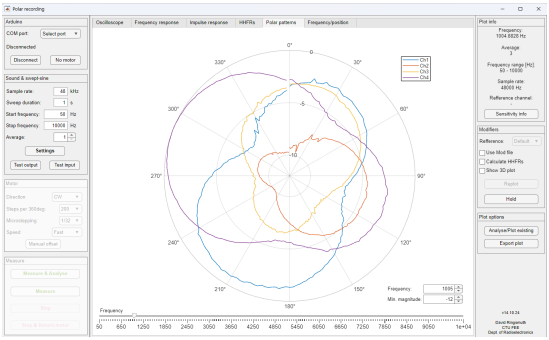

COM port: Select port
Disconnected
Sample rate: 48 kHz
Sweep duration: 1 s
Start frequency: 50 Hz
Stop frequency: 10000 Hz
Average: 1
Direction: CW
Steps per 360deg: 200
Microstepping: 1/32
Speed: Fast
Frequency: 1004.8828 Hz
Average: 3
Frequency range [Hz]: 50 - 10000
Sample rate: 48000 Hz
Refference channel: -
Refference: Default
☐ Use Mod file
☐ Calculate HHFRs
☐ Show 3D plot
Frequency: 1005
Min. magnitude: -12
v14.10.24
David Ringsmuth
CTU FEE
Dept. of Radioelectronics

Figure 1: *Application GUI*

4 CONCLUSION

The latest version of the application allows users to measure frequency responses and polar characteristics of tested microphones with configurable parameters. Users can also analyze/plot data from previous measurements as all necessary data and signals are stored in a dedicated folder.

The calculation of the higher harmonics frequency responses, used to estimate parameters of a non-linear system, is currently under development and should be available in the next release.

There are also several planned features to expand the functionalities of this application, such as an oscilloscope, spectral analyzer and signal generator.

ACKNOWLEDGEMENT

This work was supported by grant No. SGS23/185/OHK3/3T/13 of the Czech Technical University in Prague.

REFERENCES

[1] RINGSMUTH, D., K. Šimonová, V. Jandák and P. Honzík. *Bidirectional Electrostatic Microphone With Segmented Back-Plate.* In: IEEE Sensors Journal. 2024, vol. 24, no. 16, pp. 25486-25492.

[2] NOVAK, A., P. Lotton and L. Simon. *Synchronized Swept-Sine: Theory, Application and Implementation.* In: Journal of the Audio Engineering Society. 2015, vol. 63, pp. 786-798.

ČESKÁ AKUSTICKÁ SPOLEČNOST

CZECH ACOUSTICAL SOCIETY

23. 1. 2025

Acoustic measurements in scale models

David Hromas[a]

[a]Czech Technical University in Prague, Faculty of Electrical Engineering,
Technická 2, 160 00 Praha 6

`hromada3@cvut.cz`

1 INTRODUCTION

The goal of this project was to study the theory behind scale models and to test if some devices, commonly used within the human hearing range (e.g. sound card) would be sufficient tools for scale model measurement.

2 METHODS

A scale model is best defined by the ratio at which the model is scaled down (1:n). Using that ratio, the following formulas for time, frequency, and wavelength in the model are derived.

$$t_m = \frac{t_0}{n}, \tag{1}$$

$$f_m = n f_0, \tag{2}$$

$$\lambda_m = \frac{\lambda_0}{n}, \tag{3}$$

Where real parameters are marked with a subscript 0 and model parameters with a subscript m, t is time, f is frequency, λ is wavelength, and n is the scale factor.

Scale of the models is limited on both sides of the spectrum. If the model is too big, it demands a lot of resources (space, money). If it is too small, the model frequency gets too high into the ultrasound part of the spectrum, where the air acoustic absorption is high. Scale is usually chosen so that the maximum model frequency is 100 kHz. The most common ratio would be 1:10.

The materials used to construct the model should mimic the behavior of real materials within the real spectrum in the model spectrum.

3 RESULTS

Here are the results of a sound card measurement 1 and a spark source measurement 1.

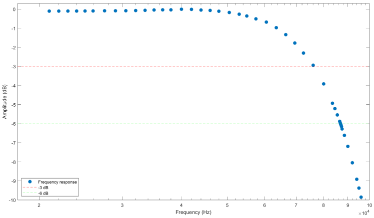


Figure 1: *Ultrasound frequency response of a soundcard.*

Source - Microphone distance (cm)	Source gap length (mm)	std Peak
120	5	0.45
120	10	0.64
60	5	0.79
60	10	0.90
30	5	0.81
30	10	0.70
10	5	1.63
10	10	5.22

Table 1: *Standard deviation of a spark source measurement.*

4 CONCLUSION

As a part of my semestral project, components of a low-cost measurement chain for scale models were tested. This work is part of a larger initiative aimed at simulating complex wave behavior for applications in room and environmental acoustics.

ACKNOWLEDGEMENT

This work was supported by my thesis supervisor Dr. Ing. Libor Husník and by Ekola group spol. s r.o., namely Ing. Ondřej Simon and Ing. Petr Novák.

REFERENCES

[1] Kolmer, F., Kyncl, J.: *Prostorová akustika. 2. nezm. vyd.*, SNTL - Nakladatelství technické literatury, Praha, 1982.

[2] Ayrault, C., Bénquin, P., Baudin, S.: Characteristics of a spark discharge as an adjustable acoustic source for scale model measurements, *Acoustics 2012*, Nantes, 2012.

ČESKÁ AKUSTICKÁ SPOLEČNOST

CZECH ACOUSTICAL SOCIETY

23. 1. 2025

Spontaneous otoacoustic emissions generated by a nonlinear cochlear model

Katerina Polakova

Czech Technical University in Prague, Faculty of Electrical Engineering,
Technicka 2, 160 00 Praha 6

`katerina.polakova@outlook.com`

1 INTRODUCTION

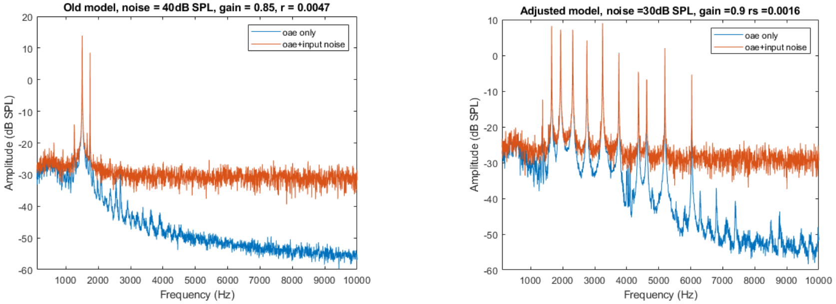
Spontaneous otoacoustic emissions (SOAEs) are signals generated in the cochlea without any external stimuli. SOAEs are present in around 70% of normally hearing adults. Details about their generation are not completely known.
Our aim is to generate SOAEs in a cochlear model in the frequency range 1-5kHz, which is typical for human ears.

2 METHODS

To generate SOAEs we used a cochlear model created by Nobili & Mammano [1, 2, 3] and later adapted, to include the middle ear, by Vencovsky et al. [4]. This model generates SOAEs only at lower frequencies (below about 2kHz).
To generate SOAEs at higher frequencies, we further adjusted the following parameters of the model: gain, gain function, irregularities in impedance along the basilar membrane.
To evoke SOAEs in the model, internal (in undamping feedback force) or external (added to the ear drum pressure) noise was presented into the model.
We found the optimal parameters by running multiple simulations on MetaCentrum grid computing in MATLAB. The duration of the simulations was 2 seconds. The input noise used was 30dB SPL (sound pressure level). The data collected was over 2 TB. Generated time domain responses were processed using filters and fast Fourier transform (FFT) to visualize and analyze SOAEs.

3 RESULTS

There was no difference in SOAEs generation based on the origin of the noise - SOAEs of the same frequencies were generated for external or internal noise.



(a) original model (b) adjusted model

Figure 1: SOAEs generated by models

Figure 1 shows the comparison between SOAEs generated by the original model (a) and the (b) adjusted model. We can see that the SOAEs are visible on higher frequencies and their number has also increased.

4 CONCLUSION

We were able to adjust the model to generate SOAEs at higher frequencies, for different sets of irregularities across the basilar membrane. This was achieved by adjusting the parameters of the model. We also confirmed that the origin of the noise (internal or external) does not influence SOAEs generation.

ACKNOWLEDGEMENT

This work was supported by the Czech Science Foundation(GACR) grant No. 23-07621J and by grant No. SGS23/185/OHK3/3T/13 of the CTU in Prague. Computational resources were provided by the e-INFRA CZ project (ID:90254), supported by the MEYS of the Czech Republic.

REFERENCES

[1] Mammano F., Nobili R.: Biophysics of the cochlea: linear approximation, *JASA*, 93(**6**), p. 3320-32, 1993.

[2] Nobili R., Mammano F.: Biophysics of the cochlea II: Stationary nonlinear phenomenology, *JASA*, 99(**4**), p. 2244-2255, 1996.

[3] Nobili R. et al.: Otoacoustic emissions from residual oscillations of the cochlear basilar membrane in a human ear model, *JARO*, 4**4**, p. 478-94, 2003.

[4] Vencovsky V. et al.: Nonlinear reflection as a cause of the short-latency component in stimulus-frequency otoacoustic emissions simulated by the methods of compression and suppression, *JASA*, 147**6**,p. 3992-4008 (2020).

ČESKÁ AKUSTICKÁ SPOLEČNOST

CZECH ACOUSTICAL SOCIETY

23. 1. 2025

Understanding radiation efficiency variances between acoustic and vibration modes.

Abhishek Singh[a,b] and Ondrej Jiricek[a]

[a]Czech Technical University in Prague, Faculty of Electrical Engineering,
Technická 2, 160 00 Praha 6
[b]Slovak Technical University in Bratislava

`singhabh@cvut.cz`

1 INTRODUCTION

The sound radiation from vibrating structures is a significant topic in the field of vibroacoustics. In practice, the analysis of sound radiation is more often performed by calculating the radiated sound power. While the determination of radiated sound is quite a commonly used parameter for radiation problems, the expression of radiation efficiency of the structure is relatively less explored. The theoretical foundation of radiation efficiency is already well-established in the literature by researchers such as Wallace [1] and Maidanik [2]. In this work, the radiation efficiency of a rectangular panel from the author's previous work[3] is determined experimentally, and a preliminary analysis of the effect of surface discretization size is discussed.

2 METHODS

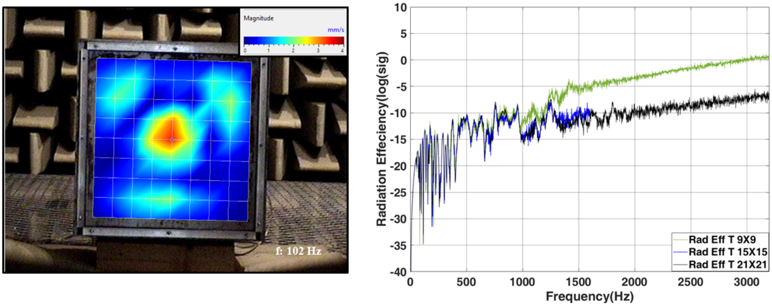
The radiation efficiency of any vibrating panel is defined with reference to the acoustic power radiated by a uniformly vibrating baffled piston.

$$\sigma = \frac{W_{rad}}{\rho c S \left\langle \overline{v^2} \right\rangle} \tag{1}$$

It is a ratio of radiated sound power from these two structures. Where W_{rad} is the radiated power, ρc is the characteristic impedance and S is the panel's surface area. $\left\langle \overline{v^2} \right\rangle$ is defined as space and time-averaged velocity.

3 RESULTS

Results from radiation efficiency show the rise as the frequency progresses. This is expected for the clamped boundaries. Grid refinement analysis provides insight into the effectiveness of efficiency. This falling trend is already discussed by Hashimoto[4], it makes physical sense as refinement of the vibration surface will lead to the requirement for Nyquist's frequency in higher frequency range.



Radiating structure

Effect of grid size

Figure 1: *Sound radiation effeciency of a rectangular clamped plate.*

4 CONCLUSION

Determination of radiation efficiency provides insight into the frequency ranges that are contributing most to the radiation. This could be helpful to know which frequency or frequency range should be treated with more concern in the problems of noise control. This approach will be improved further in future work by introducing the help of coincidence frequency determination.

ACKNOWLEDGEMENT

This work was supported by HORIZON–MSCA–2021–DN, No. 101072598 and CTU Project no: SGS25/137/OHK3/3T/13.

REFERENCES

[1] Maidanik, G. (1963). Radiation efficiency of panels. The Journal of the Acoustical Society of America, 35(1), 115-115.

[2] Wallace, C. E. (1972). Radiation resistance of a rectangular panel. The Journal of the Acoustical Society of America, 51(3B), 946-952.

[3] Singh, A., Jandak, V., Urban, D., Jiricek, O. (2024, October). Experimental verification of sound power determination methods based on radiation matrix. In INTER-NOISE and NOISE-CON Congress and Conference Proceedings (Vol. 270, No. 1, pp. 10183-10192). Institute of Noise Control Engineering.

[4] Hashimoto, N. (2001). Measurement of sound radiation efficiency by the discrete calculation method. Applied Acoustics, 62(4), 429-446.

ČESKÁ AKUSTICKÁ SPOLEČNOST
CZECH ACOUSTICAL SOCIETY
23. 1. 2025

Sound quality metrics for evaluating the sound of the fuel supply modules

Miroslava Kozlová, Ondřej Jiříček and Marek Brothánek

Czech Technical University in Prague, Faculty of Electrical Engineering, Technická 2, 160 00 Praha 6

`kozlomir@fel.cvut.cz`

1 INTRODUCTION

Sound quality metrics are widely used to evaluate various types of product sounds. Objective psychoacoustic metrics are also commonly used in the automotive industry, such as loudness, roughness, sharpness and fluctuation strength [1]. These metrics were developed based on research into human perception and describe how a particular sound is perceived from the perspective of a certain sound property. Another way of evaluating is to conduct subjective testing ("jury tests"), where specific sounds are played to human listeners, who then assign their ratings to the perceived sounds. The relationship between subjective and objective evaluations can then be used to develop specific sound quality metrics that can be used for specific product sound assessment. In this case, the selected product is a common automotive component – fuel supply module (FSM).

2 METHODS

There are many methods by which sound quality metrics (SQ) can be developed. The weighted sum method [2] and multiple linear regression were used for this experiment. The weighted sum method develops a metric as a linear combination of objective metrics with different weights, shown in formula (1),

$$SQ_i = w_{L_i} \cdot N_i + w_{S_i} \cdot S_i + w_{R_i} \cdot R_i + w_{F_i} \cdot F_i + w_{SPL_i} \cdot SPL_i \tag{1}$$

where *i* is chosen adjective pair (1-4), *w* is weight for corresponding metric, *N* is loudness value, *S* is sharpness value, *R* is roughness value, *F* is fluctuation strength value, and *SPL* is sound pressure level value.

Weights can be calculated based on the results of correlation analysis between the subjective scores and objective values for the evaluated sounds. The subjective scores in this experiment are obtained using the semantic differential method.

3 RESULTS

The results of correlation analysis between objective and subjective assessment of 5 sounds of fuel supply modules are shown in Table 1. Some values achieved correlation confirmed at a high level of confidence (shown in bold).

	Loudness N	Sharpness S	Roughness R	Fluctuation strength F	SPL (average)
Rattling/Calm	**-0.87***	**0.95****	-0.81	**-0.94****	**-0.86***
Disturbing/ Not-disturbing	-0.56	0.68	**-0.95****	**-0.95****	-0.51
Low/High	-0.82	**0.91***	-0.43	-0.63	**-0.84***
Rough/Soft	-0.82	**0.96****	**-0.86***	**-0.93****	-0.80

Table 1. *Correlation analysis: objective metrics vs. subjective scores from jury test.*
** Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.*

From the results, we observe that for adjective pair Disturbing/Not-disturbing the most significant weights are for fluctuation strength (F) and roughness (R), and for Low/High the most significant weights are for sharpness (S), loudness (L), and SPL. Based on multiple linear regression 3 linear SQ metric proposals were developed:

$$SQ_1 = -526.6 \cdot S + 1.235 \cdot F - 0.105 \cdot SPL + 11.66 \tag{2}$$

$$SQ_2 = -13.42 \cdot R + 5.943 \cdot SPL - 1.689 \cdot N + 62.06 \tag{3}$$

$$SQ_3 = -382.2 \cdot S + 11.07 \cdot SPL + 2.288 \cdot F + 0.064 \cdot R \tag{4}$$

The highest correlation between subjective and newly proposed sound quality metrics was achieved using the SQ_3 model. None of the proposed metrics reached a sufficient level of confidence to correlate with the subjective score for the adjective pair Disturbing/Not-disturbing (the rest of the adjective pairs were confirmed).

4 CONCLUSION

This experiment provides new information on FSM sound perception and proposes three linear SQ metrics. These metrics could be used for a brief psychoacoustic evaluation of this specific product sound without conducting jury tests.

ACKNOWLEDGEMENT

This work was supported by CTU project No. SGS25/137/OHK3/3T/13.

REFERENCE

[1] Miśkiewicz, Andrzej & Letowski, Tomasz. (1999). Psychoacoustics in the automotive industry. Acta Acustica united with Acustica. 85. 646-649.

[2] MORAVEC, Marek, et al. Development of psychoacoustic model based on the correlation of the subjective and objective sound quality assessment of automatic washing machines. *Applied Acoustics*, 2018, 140: 178-182.

Airborne sound insulation of lightweight partition walls in the context of sustainable development

Jiří Bečka

Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 2077/7, 166 29 Praha 6

jiri.becka@fsv.cvut.cz

1 INTRODUCTION

The research briefly presented in this study deals with the use of renewable and recycled materials in lightweight sound insulating partitions in timber-framed or prefabricated buildings. Their sound insulation is typically lower, especially in the low frequency range. The object of the research is to replace the conventional mineral fibre infill with other environmentally friendly materials and, above all, to improve the lower sound insulation level. This closely follows the trend of sustainable development that is being promoted in Europe and worldwide [1]. The research is still in process, partial results are now presented.

2 METHODS

Measurements are carried out to determine the airborne sound insulation of different infill options for a standard 125 mm thick timber partition. A standard infill of mineral wool (80 or 100 mm thick) or wood fibre (80 mm thick) is substituted with a different and more environmentally friendly infill and the difference is compared. Based on the research and the conditions of the Czech building market, the following materials were selected for the initial research:

- hemp fibre, flax fibre, sheep wool (all 80 mm),
- straw, recycled fibres – cotton/cellulose/wood fibre (all 100 mm).

The measurements were carried out in an acoustic chamber in a 'specifically small test opening'. This allows (according to the technical standard ČSN EN ISO 10140-5 [2]) measurements on smaller samples of 1.5 x 1.25 m. Wooden frames with gypsum fibreboard cladding were made.

In the second part, the measurements were repeated, but the frame was cut in half, and an air gap was created between the two halves when installed in the opening.

The sound absorption factor in the impedance (Kundt) tube was also determined for the different infills.

3 RESULTS

The length of the paper does not allow a broader presentation of the results, so it will be brief and rather limited to the result values. For the undivided frame, the values of weighted sound reduction index R_w ranged from 44.0 dB to 47.5 dB. For comparison, the panel with mineral fibre infill had a value of 45.0/45.6 dB (80/100 mm thick). The best result was achieved with recycled cellulose fibres (47.5 dB). In the case of both 80 mm and 100 mm thick infills, generally higher R-values (dB) were achieved from 500 Hz onwards.

The divided frame (which reduced the typical sound transmission through the timber elements) naturally gave an improvement in airborne sound insulation. For the new double structure (while maintaining a thickness of 125 mm), the values of weighted sound reduction index R_w ranged from 55.2 dB to 59.2 dB (the highest value was achieved again for the infill with recycled cellulose fibres). However, the weak low frequency range remains a problem.

4 CONCLUSION

Based on the data, it is possible to conclude that it is possible to successfully replace the more energy consuming mineral or wood fibre insulation with listed materials and the result will always be acoustically comparable, in many cases even better. This is also in agreement with the conclusions of reference [3].

For both frame states, the loose fill of Liapor balls was also measured. In this case, a different acoustic behaviour is seen – a significant improvement in the low frequency range, but also a decrease of the airborne sound insulation due to resonance. The material is also not practical in its settling.

It is thus interesting to focus (in the following research) on the potential of loose waste materials that will be mixed with absorbing fibres and/or further homogenised with a binder. The aim is to come up with a solution that offers the best possible airborne sound insulation results at all frequencies, allows full prefabrication and eliminates material settlement.

ACKNOWLEDGMENT

This work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS24/004/OHK1/1T/11.

REFERENCES

[1] Fetting, Constanze."The European green deal." *ESDN Report, December 2,* no. 9 (2020).

[2] EN ISO 10140-5:2021. Acoustics – Laboratory measurement of sound insulation of building elements – Part 5: Requirements for test facilities and equipment.

[3] Asdrubali, Francesco. "Survey on the acoustical properties of new sustainable materials for noise control." In *Proceedings of Euronoise,* vol. 30, pp. 1-10. 2006.

ČESKÁ AKUSTICKÁ SPOLEČNOST

CZECH ACOUSTICAL SOCIETY

23. 1. 2025

Do neural networks have space in room acoustics?

Aneta Furmanová[a,b]

[a]Czech Technical University in Prague, Faculty of Electrical Engineering,
Technická 2, 160 00 Praha 6, Czech Republic
[b]Institute of Fundamentals and Theory in Electrical Engineering, Graz
University of Technology, Inffeldgasse 18/I, 8010 Graz, Austria

furmaane@fel.cvut.cz

1 INTRODUCTION

Recently, machine and deep learning techniques have gained attention in the fields of physics and acoustics. This paper focuses on Physics Informed Neural Networks (PINNs), and their applications, namely in room acoustics.

In PINNs, first proposed in [1], the goal is to learn a neural network that would approximate the solution of the governing partial differential equations (PDEs).

The main idea of how to prevent a NN from violating known physics was to include a new loss term, which is built as a residual of a known PDE. It allows training on smaller amount of data , which makes PINNs a powerful tool data-scarce fields. However, the non-trivial loss terms leads to more complicated loss landscape, which causes poor performance. Hence, other learning strategies than used for classical NN has to be considered [4].

2 PINNS IN ROOM ACOUSTICS

PINNs can be applied to solve both forward and inverse problems. Although conventional methods like Finite Element Method (FEM) could be more suitable for the forward problem, PINNs could offer more efficient approach for inverse problems, such as inferring boundary conditions or material properties from measurements. So far, many papers focused on PDE solutions in 1D or 2D space. The study on the feasibility of extending PINNs to solve the Helmholtz equation in 3D was performed in [3], with implementation in DeepXDE framework [2]. This library is helpful for prototyping a PINN, but the possibility of tweaking the setup of DeepXDE implementation is limited. Hence, the next

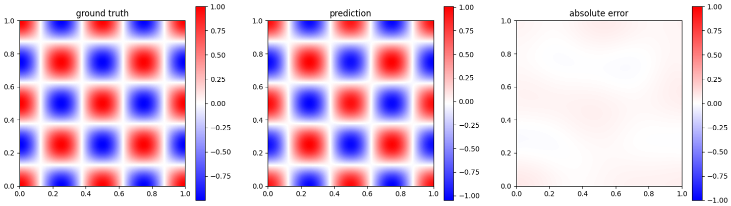


Figure 1: *Example of achieved results with own PINN architecture.*

step is to develop a custom framework specific to the Helmholtz equation in 3D, allowing a more focused study of the problem.

3 RESULTS & CONCLUSION

A PINN framework in PyTorch for both 2D and 3D cases was developed to replace the DeepXDE implementation, allowing more custom features and providing more insight into the training process through trained layers visualizations. This implementation includes, e.g., layer-wise locally adaptive activation functions (L-LAAF) and adaptive learning rate, which were not provided by DeepXDE at the time for the PyTorch backend. The most challenging part was implementation of Neumann boundary condition for a cube.

So far, the PINN was trained on an analytical solution. The achieved relative error was about 6 %, which was reached with a vanilla PINN approach shortly after 3200 epochs. For the result, see Figure 1. However, the optimizer struggled to converge. This issue was already pointed out in [4] and many others, and is known to be caused by the non-trivial loss landscape. Therefore, new training strategies have to be implemented to overcome these complications. Future work includes training on a dataset generated by FEM for sharper excitations and introducing more knowledge to the background.

REFERENCES

[1] M. Raissi, P. Perdikaris, G.E. Karniadakis, (2019). Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations. *J. Comput. Phys.*, 378, 686–707. DOI: 10.1016/j.jcp.2018.10.045.

[2] L. Lu, X. Meng, Z. Mao, G.E. Karniadakis, (2021). DeepXDE: A deep learning library for solving differential equations. *SIAM Rev.*, 63(1), 208–228. DOI: 10.1137/19m1274067.

[3] S. Schoder, F. Kraxberger, (2024). Feasibility study on solving the Helmholtz equation in 3D with PINNs. *arXiv preprint* arXiv:2403.06623.

[4] A. S. Krishnapriyan, A. Gholami, S. Zhe, R. M. Kirby, M. W. Mahoney, (2021). Characterizing possible failure modes in physics-informed neural networks. *arXiv*, arXiv:2109.01050.