Abstract

This dissertation presents novel methodologies using machine learning, including deep learning and generative artificial intelligence, for the analysis and modeling of acoustic parameters of pipe organs and flue pipes. In particular, it focuses on the prediction of blowing pressure in pipe organs, modeling the impact of pipe placement on the windchest on the basic parameters of the sound generated by flue pipes, and the classification of their labium types. Based on data analysis, innovative mathematical models have been developed in this work, as well as machine learning - including deep learning - algorithms, which enable precise prediction of physical parameter values, such as blowing pressure, based on acoustic and geometric attributes of the flue pipes. Additionally, the use of advanced sound signal analysis techniques allowed for the automatic classification of pipe mouth types with high accuracy, using audio and spectral data.

The presented research also includes the analysis of the influence of the surroundings of the pipes, such as the presence of obstacles near the labia, on airflow parameters and the generated sound. Non-invasive measurement methods based on interval calculus, combined with regression models, enabled quantitative description of this phenomenon and its impact on the fundamental frequency and harmonic structure of the generated sound. Modeling these effects allows for better understanding of the interactions between the physical components of the instrument, which is important for optimizing tuning and instrument design processes.

An important aspect of the work is the implementation of algorithms for precise prediction of blowing pressure in a pipe organ, based on a limited set of physical and acoustic data. These methods use regression techniques and artificial neural networks, as well as generative artificial intelligence, bringing new automation possibilities and facilitating organ reconstruction and restoration. Additionally, the acoustic theory was extended with formulas using

sound parameters, taking into account the influence of the obstacle's distance on the sound generated by flue pipes. These formulas are the result of research based on the analysis of spectral and time-frequency parameters of sound signals from labial pipes.

The obtained results provide innovative methods for analyzing acoustic and physical data of musical instruments, aligning with modern trends in computer science, where advanced machine learning models and generative artificial intelligence are used to solve engineering and acoustic problems. This work contributes to the development of the interdisciplinary research, combining computational algorithms with the physics of wind instruments and music theory, offering new research perspectives and practical methods for organ builders and acousticians. Conducting such research would not have been possible without the author's theoretical and practical musical knowledge, as well as experience in organ playing, which enabled the synergy of advanced algorithms with organology and helped proving the research theses.

The research theses, posed in this dissertation, have been confirmed and proven in the published papers. First, it has been demonstrated that the presence of an obstacle near the labia of a flue pipe causes measurable and predictable changes in basic acoustic parameters, such as fundamental frequency and sound level, which has been described by a formula allowing quantitative determining of this phenomenon. Second, the change in the fundamental frequency of the flue pipe’s sound, caused by the proximity of an obstacle, can be effectively modeled, using interval calculus and logarithmic regression. Third, deep neural networks trained as part of the carried research have proven effective in classifying the types of organ pipe labia based on acoustic features, achieving high recognition accuracy. Finally, machine learning models and generative artificial intelligence applied in this research allowed precise estimation of the blowing pressure in a pipe organ, based on physical parameters of flue pipes and their fundamental frequency, also for incomplete instruments.

The theses posed in this dissertation were not only thoroughly verified and discussed in the attached scientific publications, but also tested and confirmed in practice. The implementation of the proposed solutions in real restoration projects, such as the reconstruction of the unique chest organ from the co-cathedral of St. John in Kamień Pomorski, proves the effectiveness and practical value of the developed methods. The proposed methodologies have been practically applied, thus going beyond the theoretical domain, and yielding real effects in conservation processes and the daily work of organ builders. Such an approach offers significant support for both cultural heritage preservation and the development of modern information technologies in the field of acoustics and musical instrument modeling.