Characterisation and Modelling of Vibration Handheld Probes for Building Acoustics with Non-parametric Statistics and Machine Learning

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Resumen:

Airborne sound insulation (ASI) assessment is still a challenge in Building Acoustics (BA). Traditionally, sound pressure is the central parameter to estimate Sound reduction indexes and is still extensively used with regulatory goals. However, sound pressure might not be robust enough depending on the sound field interactions in rooms and on the specific application. The main reason is the lack of pure diffusivity of the sound fields, notably in the low-frequency range. Besides, classic pressure methods do not usually consider the flanking transmission in rooms, which may hamper both the scope and correct implementation of optimal solutions. Furthermore, BA designs are being required more sustainable, and light materials are becoming a significant player in construction, which remarks the flanking transmission between rooms. Due to these requirements, most related standards were updated since 2017. However, testing standards from ISO 10848 series are still far from practical application in situ.

Hence, vibration in BA has received attention in recent years, and this research field is active. Ample evidence support that vibration signal on walls is relevant both for ASI assessment of a single wall without flanking influence and to provide proper input variables into calculation frameworks. Most studies have focused mainly on advanced techniques, as laser vibrometry, or destructive mounting methods as studs for accelerometers. Still, while such techniques may be of great value, they are challenging to perform in realistic environments, due to equipment specifications and costs, and also the time that must be invested in collecting data. Those techniques require quite large numbers of accelerometer positions for measurements and the desirability of methods that obviate tedious and impractical testing techniques. Vibration handheld probes based on one-axis accelerometers are simple and cost-effective solutions. They allow many practitioners to use them affordably and is a less intrusive and operative mounting technique.

The objective of this Thesis is to develop tools for improving data collection from the vibration signal in BA applications. Thus, the estimation and design of ASI might be more efficient. To that end, non-parametric statistics and machine learning (ML) algorithms are designed to enhance the use of vibration handheld probes.

Available information on handheld probes performance is scarce and scattered concerning frequency response, resonance or repeatability. To that end, firstly, this Thesis has built a novel database that aims to provide reliable data about these sensors. This dataset contains experiments that simulate vibration signal collection in practical cases without the need for vibrating walls. In sum, 90 different sensor setups are fully reported.

Secondly, an innovative in situ procedure for the characterisation of the inherent noise of measurement systems is proposed. In BA, the vibration signal levels might be faint. Flanking elements are not airborne-straight excited, and background noise (BN) signal levels must be considered in the measurement. Some of the required data is not always available in manufacturers technical specifications, and they are hard to find out or challenging to check in regular engineering work.

The experiments presented an increase of inherent noise with hand movements, remarkably at low frequencies, while the high-frequency range is mostly influenced by sensor sensitivity. These results underline that the signal-to-noise ratio of the sensor might be relevant in vibration measurements in BA.

Then, a new and straight sensor characterisation procedure is presented to study the vibration frequency response of probes, depending on the mounting technique and its comparison to a more robust wax fixing method. Handheld probes modify their accelerometers response, mainly due to the probe length and the material. Sensor size, weight and connector location were also observed as influencing variables, in addition to others, such as operator hand tremor and the way the sensor is held.

Nevertheless, a study of all these variables would provide a very complex model. Thus, this research employed a statistical approach to simplify the characterisation tasks. In BA vibration, a Gaussian probability distribution is usually assumed in the collected data, although not being right in all cases. An innovative Boot strap approach was, thus, employed in this study without any assumptions on data probability distribution. Bootstrap is a non-parametric statistic method that provides further information than typical average values on a particular experimental population when the real population is unknown and difficult to estimate. Bootstrap statistical mean and its confidence interval are used as performance indexes. Up to 90 probe types and sensor setups were characterised according to their frequency response and repeatability in a real environment, as compared to regular wax fixing. Probes show worse repeatability than waxed or simply handheld broadband techniques, but 95% Bootstrap statistical mean confidence intervals were less than 0.5 dB in the low-frequency range, up to a maximum of 3.8 dB at higher frequency bands of interest. Higher deviations are found in system resonance. However, uncertainty values on repeatability in BA are not far from these values. A good similarity is found in the useful bandwidth of the probe, ranging from 50 Hz to 800 Hz-1 kHz, depending on the features of the probe. Bootstrap statistical mean is useful to correct the deviations of measurements in the frequency response. This probe data approach can provide more efficient resources management in real test situations.

Finally, this Thesis worked on the prediction of the vibration frequency response of handheld probes. A novel approach that involves ML and readily available data from probes was explored. Vibration probes are efficient and affordable devices that provide information about testing ASI in BA. However, fixing a probe to a vibrating surface shifts sensor resonances and change the estimation of levels. Thus, the calibration response of the included sensor in a probe differs from the frequency response of that same probe. Simulation techniques of complex mechanical systems may describe this issue, but they count on hardly obtainable parameters, ultimately restricting the model. Thus, this study discusses an alternative method, which comprises different parts. Firstly, the vibration frequency responses of 85 probes were labelled according to six features. Then, Linear Regression, Decision Tree Regression (DTR) and Artificial Neural Networks algorithms were analysed. It was revealed that DTR is the more appropriate technique for this data.

The best DTR models, in terms of scores and model structure, were fine-tuned. Eventually, the final suggested model employs only four out of the six original features. A trade-off solution that involved a simple structure, an interpretable model and accurate predictions, was accomplished. It showed a maximum average deviation from test measurements ranging from 0.6 dB at low frequencies to 3 dB in the high-frequency range while remaining at a low computational load. This research developed an original and reliable prediction tool that provides the vibration frequency response of handheld probes.

This Thesis presents research to support the use of vibration handheld probes in BA. The applied characterisation and modelling techniques for these sensors provide a robust and alternative framework for vibration measurements. Thus, this study is a step ahead for ASI assessment from another point of view that might simplify, and improve the testing methods, but also make them affordable.