Acoustic documentation of church organs

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Abstract

The method for acoustic measurements of organs, developed in 1991 at VUZORT, enables a description of the sound of all organ pipes measured *in situ*. The method follows an idea of Lottermoser. The measurement equipment is based on a personal computer, equipped with a signal processor board. The organ is played by an organist, and the software-controlled measurement procedure follows a scheme prepared according to the specification of the particular instrument. The control program involves digital conversion and storage of the sampled sounds, followed by a computation and processing of the amplitude spectrum. The system enables measuring and processing of both the transient and the quasi-stationary parts of the organ sound (single tones, triads of neighbouring semitones), and of the background room noise. The acoustic response of the church is measured by means of the MLSSA measurement system. The probability model of the acoustic pressure distribution in large rooms like churches has been verified. Using this model, the minimum number of microphones needed for the acoustic measurements with the required accuracy, was determined. Up to now, our method has been used to document the sound of 11 church organs.

Introduction

There are several thousand pipe organs in the Czech Republic, at least 50 of them are very valuable. Many rare historical instruments come from the Baroque period, most of them have kept the original specification of stops. The condition of Czech organs has become worse during the last 50 years, a big amount of them are in critical condition. The documentation of the sound state of old instruments can help to save their original sound.

This situation has lead us to state our research project. Its first step was to prepare a method for acoustic documentation of organs.

Description and properties of the documentation method

Acoustic documentation of organs according to our method involves several measurement types shown in the left part of the Fig.1. The measurement result is a special record of the sound state of all pipes and all plenums of the instrument. The types of data stored are shown in the right column in Fig.1. The stored data enabled us to study sound properties of the instrument in the following hierarchy: **plenum - stop - tone**.

The in situ measurement has been chosen for the organ sound documentation. Thus the influence of acoustical properties of the room is fully involved. The measurement equipment is based on a personal computer, equipped with a DAP board with an A/D convertor and signal processor. The real time measurement and digitalisation is possible without any necessity of sound recording. Time signals (acoustic pressure levels) are picked up by microphones.

The base of the acoustic documentation is the **measurement of quasi-steady-state parts of the tones for all stops and plenums**. The triads of neighbouring semitones are measured in the same time following Lottermoser's ideas (Lottermoser & Meyer, 1966; Lottermoser, 1983/a,b) for organ plenums measurement. Acoustic signals are picked up by three microphones, which are placed in the typical listening position in a church, 4 m above the floor. A mean amplitude spectrum calculated in the real time is saved and the time signal of the first microphone as well. The **measurement of starting transients of c-tones of all organ stops** is an important part of the documentation. Acoustic signals are picked up by two microphones; the first one in the same position as during the stationary measurement, the second above the organists position. **The background room noise including the wind noise** is recorded at the beginning and at the end of the measurement. The acoustic response of the church is measured by means of the MLSSA measurement system (Rife, 1987-90). The **impulse responses** are used to calculate the reverberation time.

We have created a PC program which controls the measurement procedure according to parameters which are concentrated in a parameter file. The file respects the specification of stops of a documented instrument and it contains other information on acquisition and

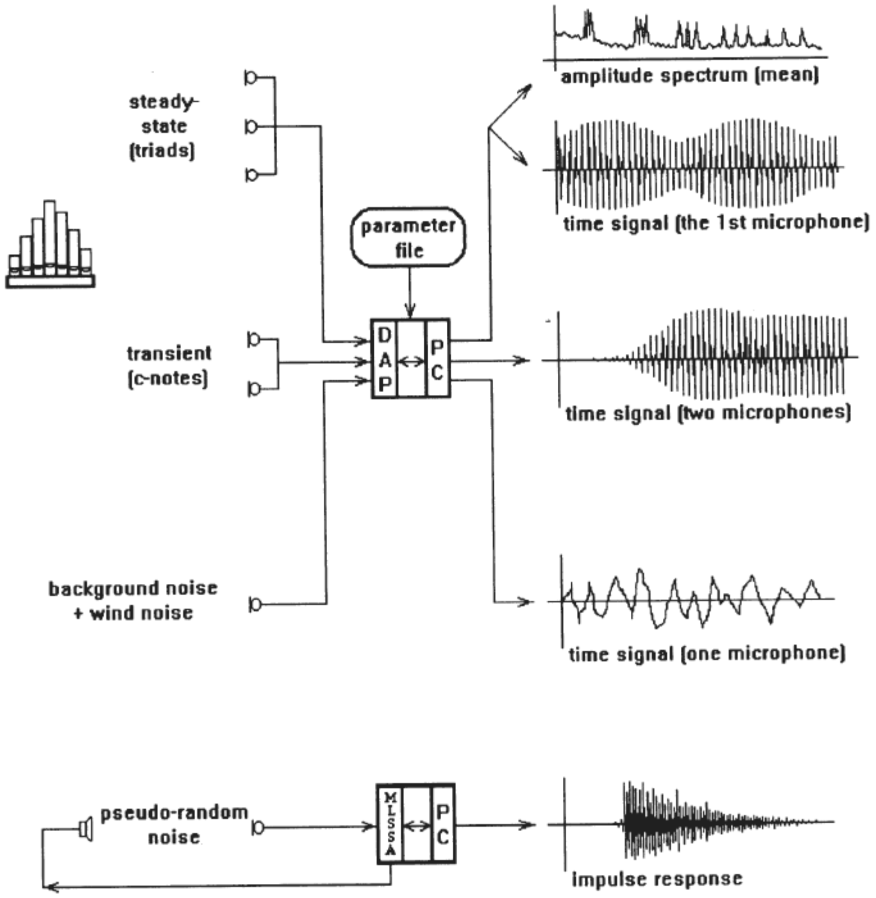

Figure 1: Organ acoustic documentation system

data processing. Our program generates the names of the saved data files according to the parameter file and so it is possible at first to manage the huge measurement amount, and second to evaluate the huge data amount. To show the demands of an organ documentation let us say that the measurement is created by a group of 3 men, the whole measurement procedure takes about 10 hours for an organ with 20 stops, its data represents about 1500 data files which take more than 30 MB.

Some problems solved developing the method

a) The number of microphone positions

Our method respects not only documenting and the organ builder's point of view, but also the physical one. One of the basic properties of every physical measurement method is its repeatability.

The first organ experimental measurement was in Saint Kliment church in Prague. We measured the SPL of stationary c-tones in the Diapason 8 feet of the Great organ with one microphone. Several measurements were made with the microphone in the fixed position, others in the close neighbourhood of this position and others in very distant positions in the church. The amplitude spectrum was calculated and the range of amplitudes of partial tones for frequencies in a band from 100 Hz to 2 kHz were evaluated. The range hardly exceeded 2 dB with the fixed microphone position, but it exceeded even 20 dB very often using different microphone positions, close or distant.

To determine the number of the microphones for the measurement with the predefined accuracy we have formulated and verified a **probability model of an acoustic field in a large closed room**.

As it is known an amplitude of an acoustic pressure of standing waves is a function of cosines of a distance from a reflecting wall (Kuttruff, 1973). In the real space the local minima are not the same, but the deeper they are, the sharper (more narrow) they are, on the contrary the local maxima are wide and flat. These ideas have led us to formulate the **hypothesis**:

The probability distribution of SPL in a large closed room is independent on frequency, with one peak and non-symmetric. The probability density acquires its maximum in the upper half of the SPL range.

To verify this hypothesis we did the following

Table 1: Sinus signal measurements

measured frequency [Hz]	65	131	262	523	1046	2093	4186
range of SPL values [dB]	22.5	23.0	30.5	27.0	24.0	31.0	28.0
sum of ranks [-]	334.5	352.3	353.4	362.9	341.0	352.9	356.5
Perr for 1 microphone [-]	.28	.44	.49	.53	.57	.56	.51

measurements in Saint Nicolaus' Baroque church in Prague: In the middle of the listening area, 4 m above the floor, it is out of the church acoustic structures influence, we took the square net 10 times 10 points in a half meter distance. We have measured the acoustic pressure level of the sinus signal (which source was placed near the organ) in all net points. The frequencies measured are in Tab.1. The range of the acoustic pressure level for individual frequencies varied from 22.5 to 31.0 dB (Tab.1). The SPL distribution for 131 Hz frequency is given on the 3 dimensions picture (Fig.2), where we can see several local minima, it means that the measured area was large enough. The SPL distribution in the area is sufficiently sampled by the chosen net density. The results get the character of random samples for higher frequencies.

We have verified the independence on frequency of the SPL distribution with the help of the mathematical statistics method: we used the nonparametric Kruskal-Wallis test for one-way analysis of variance (Norusis, 1986). The sums of ranks for individual frequencies are involved in Tab.1. The significance level of equality of the SPL distributions is 0.97.

Next we have joined the measured values for each frequency to 2 dB bands. The statistical frequencies (they are the numbers of occurrences) of the SPL values in individual bands are shown on the Fig.3. If we take the relative statistical frequencies for the estimation of the probabilities of SPL occurrence in the individual bands we can consider the hypothesis to be verified.

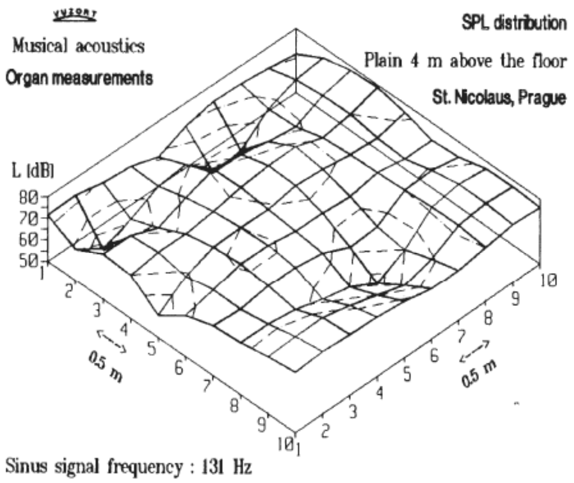

Figure 2: SPL distribution
The solid lines connect measured SPL values, The broken lines connect the same SPL values

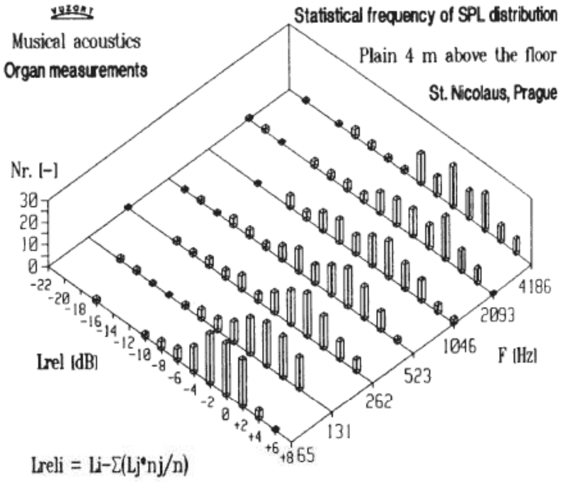

Figure 3: Statistical frequency of SPL distribution.
Lrel are the deviations of the band centres from the band of the average value; Nr. are the statistical frequencies

Then we have estimated the measurement error probability. We have taken the measurement for success if its result lay in the predefined interval whose centre is the mean value of the SPL. Relative statistical frequency of unsuccessful measurements represents the estimation of an error probability for one microphone measurement. The estimate for 7 followed frequencies and for the ± 3 dB interval moves between 0.28 and 0.57 (Tab.1). To estimate the measurement error for n microphones we have supposed the measurement results to be statistically independent. The measurement error probability for 1 to 7 microphones in the ± 3 dB interval shows Fig.4. After the evaluation of the results of the sinus signal we have measured several c-tones in the Diapason 8 feet of the Great organ. If we evaluate the variability of the individual partial tone amplitudes in the band from 60 Hz to 4 kHz,

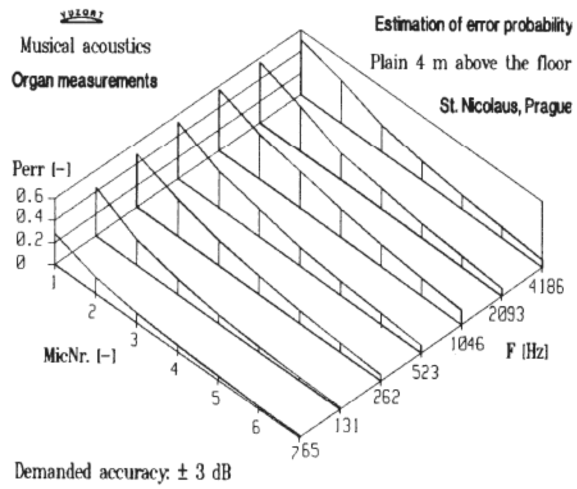

Figure 4: Estimation of error probability for 1 to 7 microphones

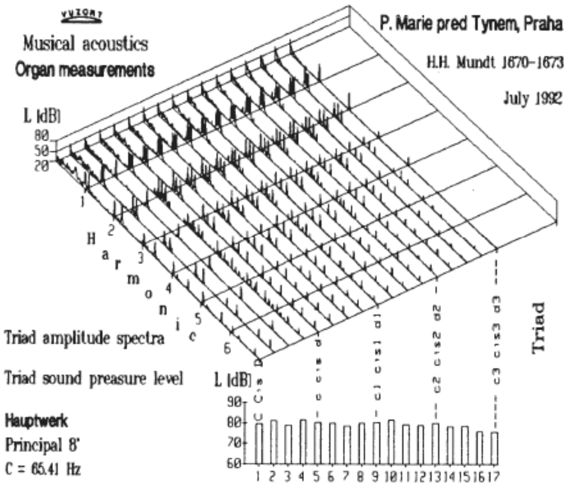

Figure 5: Graphical presentation of an organ stop documentation
Hans Heinrich Mundt organ in the Church of Our Lady before Tyn

we obtain the close agreement with our probability model both for one and the average of three microphones.

b) The sample rate determination

The compass of organ tones exceeds 8 octaves very often. For the measurement of steady-state parts of tones it is convenient to adapt the sample rate to the foot length stop. We have defined the **sliding sample rate** which changes fluently according to the fundamental frequency of each measured triad tones. So the spectrum can contain the same number of partial tones keeping the same distinguishability of the individual partial tones for all measured triads. The sliding sample rate enables a well arranged results picture, Fig.5 gives an example of the graphical presentation of an organ stop measurement result. The partial tones are on the same positions for all individual triads spectra. The sliding sample rate idea looks very useful for the different tones spectra comparison and statistical evaluation. It is possible to identify six partials of the individual tones in the triad, starting with the seventh partial tone they get mixed. The SPL values for the individual triads given in Fig.5 are reduced to one tone.

Conclusion

We have already documented 11 instruments the way described above.

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