

## INTON – A SYSTEM FOR IN-SITU MEASUREMENT OF THE PIPE ORGAN

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### ABSTRACT

The article presents the design and capabilities of the *Inton* measurement system. The system is developed in MARC Prague for an in-situ repeatable unbiased acoustical documentation of sound condition of pipe organs and for the analysis of the organ pipe sounds in the process of organ building and voicing. The organ sound documentation is independent on the precise actual placing of the microphones in the space. In addition to the usual review of spectra of the individual pipes the system allows to evaluate balance of the tone sound quality within registers of an organ, to discover out-of-tendency tones and to assess the room acoustic parameters from the point of view of an organ position in the space without any other equipment. The system consists of a microphone set, microphone pre-amplifiers, A/D converters and two laptop computers with special software.

The system was already used for the subsequent objective and/or subjective evaluations and comparisons of documented sounds after a long time pause. Some organ builders in CZ employ *Inton* as a tool in various stages of the organ building or restoration techniques. The *Inton* measurement of room acoustics using the pipe organ as a sound source is used at present in a research project to extend the *Inton* utilities.

### 1. INTRODUCTION

Sounds of pipe organ are each time joined with properties of the space where the instrument is placed. That is why the organ sounds can not be measured in an anechoic room. The repeated in-situ recordings of pipe organ tones with one microphone in a fixed place in a room and the following signal analysis show changes of obtained results with barometric pressure, temperature and humidity. The sound spectra are changed due to the changes of sound radiation conditions in the room which also changes the standing wave trajectories and the sound pressure distribution (sound field) in the room [1]. Furthermore, it is not possible to place the microphone in an exactly equal position upon repetition. Then the comparisons of repeated measurement made with one microphone are not accurate enough. Therefore, „The method of the acoustical documentation of pipe organs“ was developed (first presented in [1], later extended [2] only in Czech). Both the operating procedures based on this method and the necessary hardware were joined in one measurement system presented in this article. The system design was realized in MARC Prague and the abilities were proven in cooperation with organ builder specialists. The system is frequently used in voicing process (voicing = intonace in Czech language), after that the name *Inton* was established.

Pipe organs are very complex musical instrument. In an organ assembly, the pipe voicing must keep both the suitable sound quality and loudness relationships of separate pipes of a tone between different registers and also the suitable harmony of the pipe soundings within the tones of a single register (balance of tones [7]). The suitable balance of tones is connected with room acoustics. The historical evolution of pipe organs brought a common convention in preferred organ sound, and the listeners of organ music expect some suitable fluent changes in tone sound according to the pitch changes. But a quantification of this expectation is difficult because the balance is based on intuitive subjective feelings only. Experienced organ voicers hold a concept about such fluent changes within tone sounds in their mind to realize it accordingly. The appraisal of actual tone balance by a voicer only in in-situ listening is exhausting. The correct balance evaluation is practically impossible after one hour listening without a pause. Therefore the *Inton* software was extended with a graphical balance screening utility based on spectral analysis of signals of individual pipe in registers. The utility also enables a detection of the tones which are out-of-tendency from the fluent changes of tone spectra needed for the loudness and sound quality balance of organ registers. If the sound of an organ is listened to, and subjectively judged after a time (e.g. by members of a committee after an organ repair or restore) the listeners usually do not agree with each other (a person memorizes only an individually stylized reflection of listened sounds). The *Inton* system allows tone comparisons in both in subjective listening tests and in objective spectral characteristic matching.

### 2. HARDWARE

The *Inton* hardware is a modular system built from standard components (see Fig. 1) allowing easy system configuration according to the specific measurement needs and the utilization and the re-use of the equipment which is readily available to the user. The *Inton* hardware consists of a microphone set, microphone pre-amplifiers, a multi-channel A/D converter, a server computer for audio data digitization and a client computer for system control, data processing, visualizations and archiving. Both computers are interconnected via wired or wireless ethernet network. All components are ordinarily market available without a special claim.

#### 2.1 Microphones

The basic microphone set consists of three omni-directional microphones. The set acceptable minimises negative effects of standing waves. This basic microphone set is suitable for the objective acoustical documentation and analysis.

Recordings for the subjective listening tests require binaural microphones (dummy heads). As an alternative, standard microphone pairs in AB configuration with narrow base can also be used.

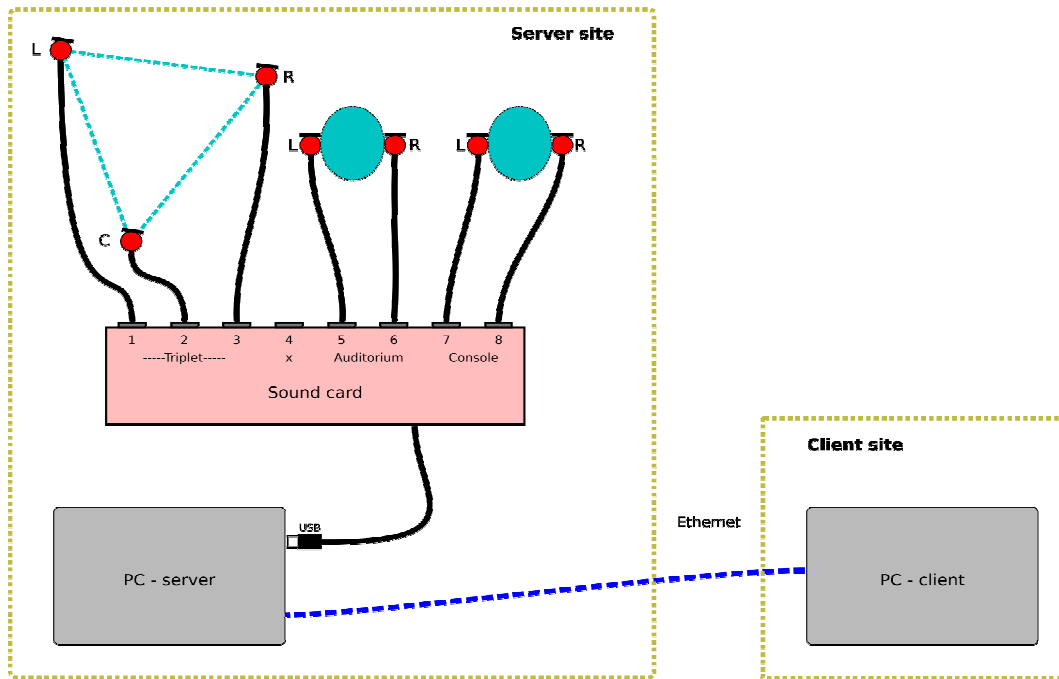


Figure 1: Inton hardware schematics

## 2.2 Pre-amplifiers & A/D converters

Microphone pre-amplifiers, phantom power supplies and A/D converters can be integrated in an external sound card with USB interface. Sound cards with 24 bits quantisation, sample frequency 96 kHz and flat frequency response 20 Hz – 20 kHz  $\pm$  0.5 dB fulfil requirements for the measurement dynamic and frequency range.

## 2.3 Computers

Digitized signals from the sound card are fed to a laptop computer with the software for data acquisition, transfer and storage (IntonASIOserver program). This *Server* computer with the sound card can be placed in the space with respect to optimal microphones wiring (usually placed on a typical listening place in a nave).

Data from the server are transmitted to the remote computer (client) via wired or wireless ethernet network. The *Client* computer with the special software (Intonclient program) serves for the data processing, analysis, visualization and archiving as well as for the system control. Separation of the client computer from the rest of the system facilitates physical manipulation with this control computer during the measurement. The client computer can be placed in a suitable position at the organ console to be easily accessible during the playing the keyboards or stop tabs manipulations. Wireless connection allows free manipulation with the client computer during measurement, e.g. the organ builder can control the process during the voicing the pipes inside of organ.

## 3. SOFTWARE

Software for the pipe organ sound recording and analysis is divided into two separate programs, each running on the dedicated computer.

## 3.1 Server

IntonASIOserver program is used for the acoustical signals digitization and transmission. Program runs autonomously on the server computer and is controlled using commands being sent from the client computer via UDP protocol. Audio data are transferred to the client computer via TCP channel.

## 3.2 Client

Intonclient program serves for the user interface, received data storage, immediate processing, automatic analysis, visualization and archiving. Inton graphical output allows fast visual evaluation of the tones spectral characteristics and registers evenness and balance (for more see [7]). Spectral analysis results can be stored in the numerical and the graphical form. Recorded sound samples and analysed data are stored in the format suitable for the acoustical documentation results export into the central database of historical organs in the Czech Republic.

The client program can be run in two operational modes. In the *on-line* mode is the client computer connected via the ethernet network with the server which upon request sends digitalised audio signals for the processing, visualization and storage. In the *off-line* mode the client computer runs independently and allows the access to the stored data, the visualisation, post-processing and storage. In the *off-line* mode e.g. new analyses can be performed and added.

It is possible to customize the measurement parameters as well as the program user interface and the graphical output look.

Main program window contains graphical output of the spectral analysis results. Spectra of all tones from selected register can be displayed in various forms (Figs. 2 and 3). Each sound sample spectrum is displayed as a coloured bar placed above the corresponding key. The colours represent the frequency components amplitude; vertical positions correspond with the frequencies. The position of the bar bottom edge indicates the fundamental frequency of the tone.

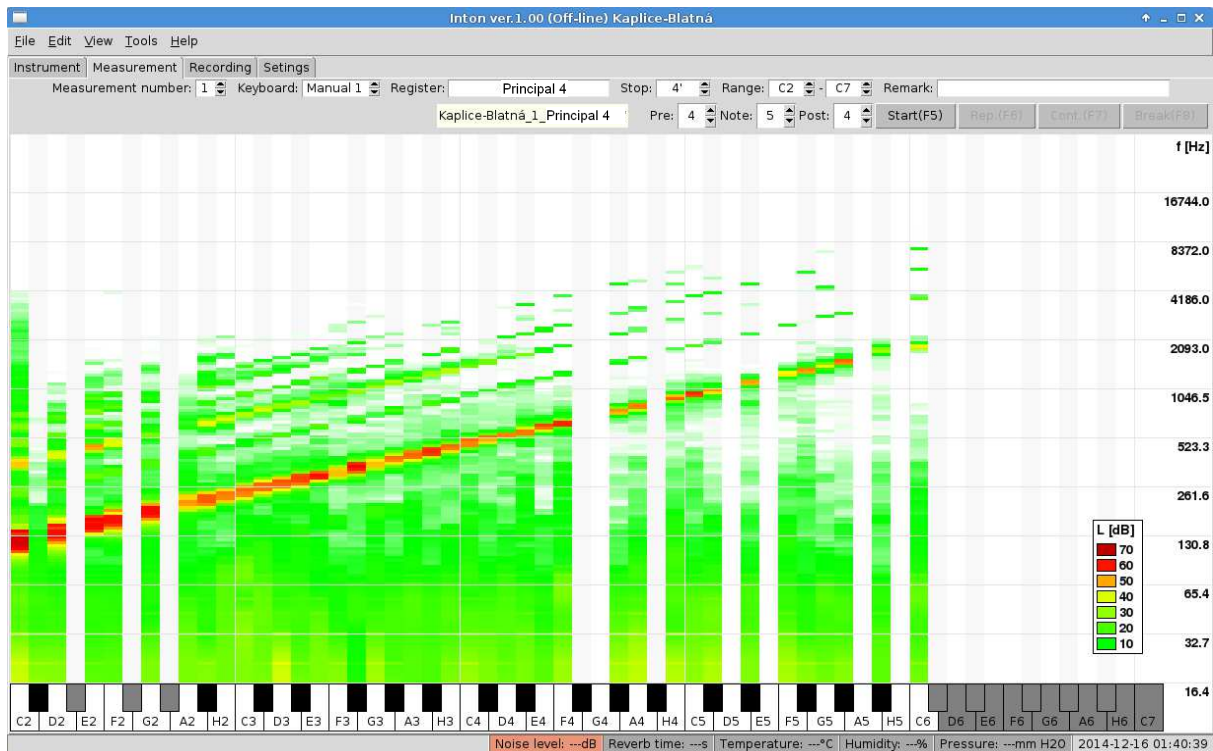


Figure 3: An example of FFT spectra of the Principal 4' register (grayed keyboard keys were assigned “not to play”; white columns above non gray keys show not played tones up to now; 2<sup>th</sup> left column presents a non sounding pipe; the tones A2, F3, G3, C5, A#5 are examples of out-of-tendency tones)

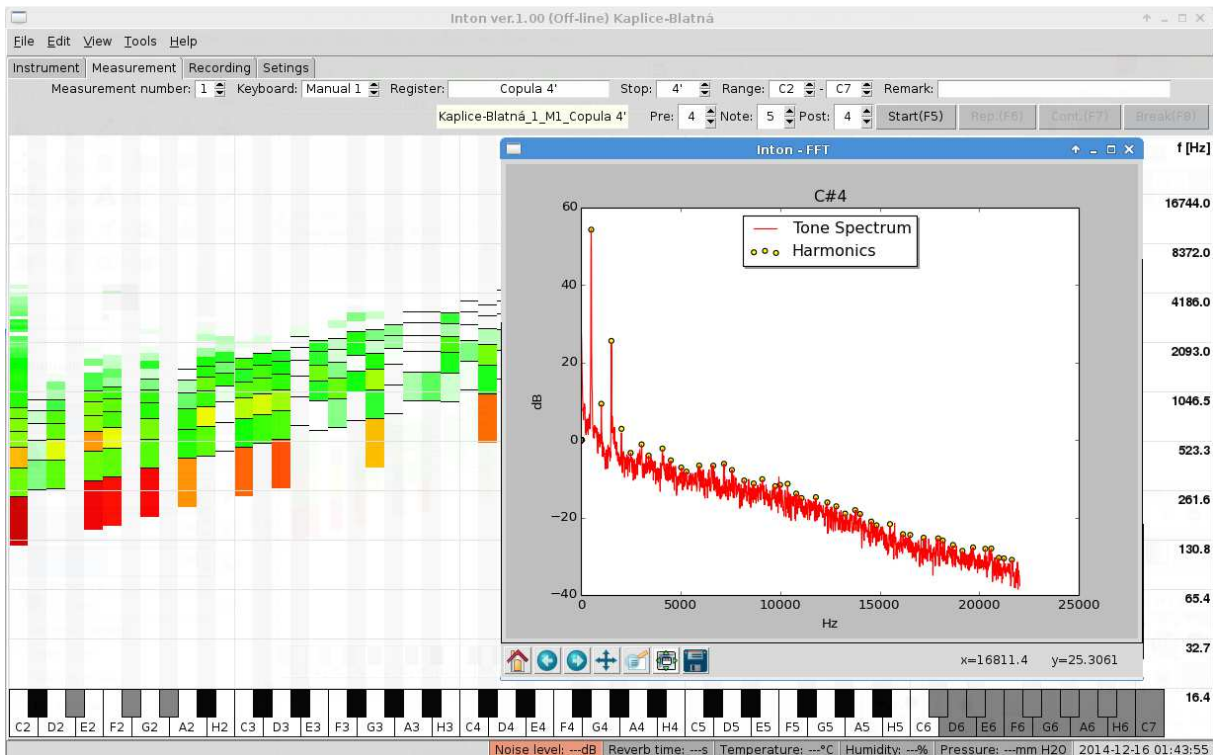


Figure 2: Harmonic spectra of the register and FFT spectrum with harmonics for selected tone C#4

The graph in Fig. 3 displays an example of different view on spectra for a selected tone (in this way an additional information can be displayed including time courses of separate microphone signals, fundamental frequency, harmonics spectra, etc.).

Program contains a simple audio recorder allowing the recording of sound examples or other samples without sound analysis.

Recorded sound samples and analysed data are stored in the format suitable for the acoustical documentation result exports into a central database.

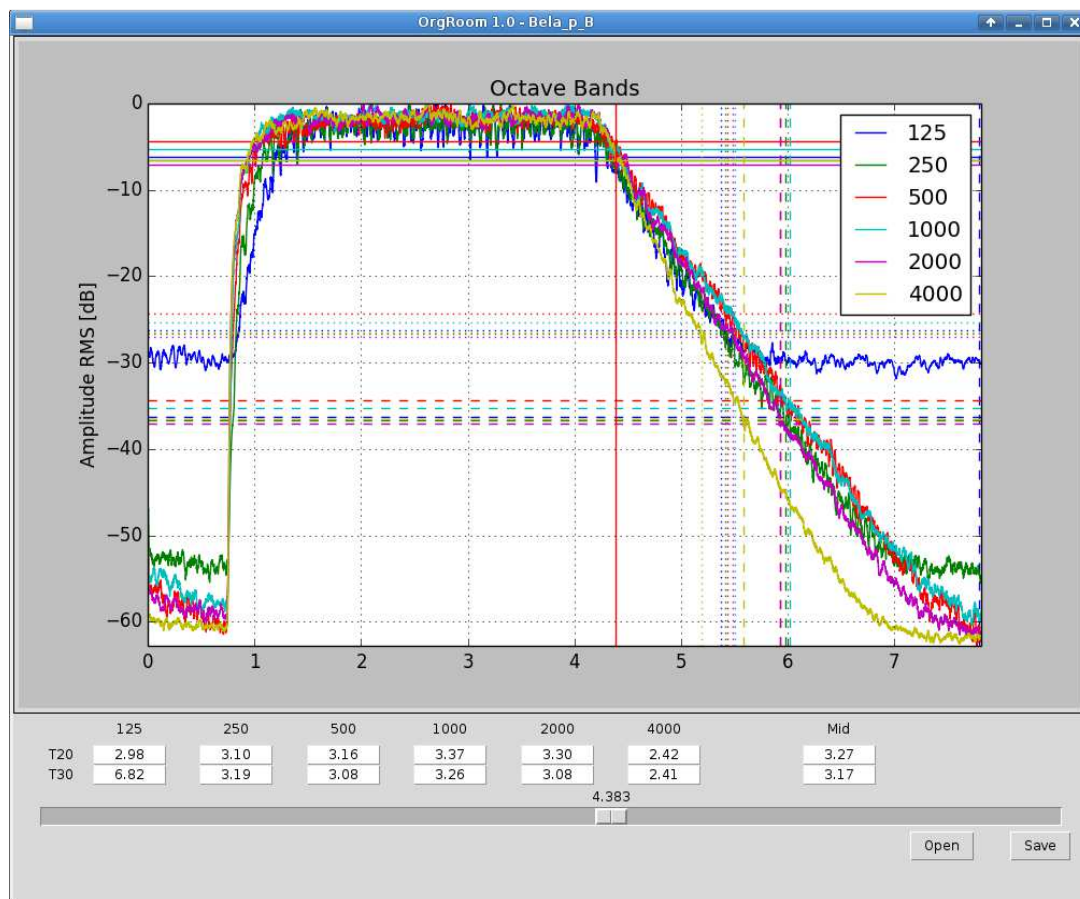


Figure 4: Time course of sound pressure decays (sound signals filtered in octave bands, middle frequencies see legend)

#### 4. THE SYSTEM USE

The tones of individual registers are played by a Inton operator on a real organ keyboard and produced sounds are recorded by the Inton system. The user interface of the Inton software instructs the operator about the selected register and tone height to be played (as a single note or as a sequence of pre-selected tones assigned by operator on a keyboard of the user interface; an example of pre-selected tones see in Figs. 2, 3 bottom, the non played tone keys are on the keyboard in gray). The instant automatic signal analysis and the graphical presentation of the results in various forms are done automatically. The operator can select from different types of results visualization (an example of a spectral view see in separate frame in Fig. 3) during the organ building, restoration or documentation according to a process in progress (voicing, pipes adjustment, tuning, interventions effects assessment, etc.). One of these visualizations is a special 3D spectral graph of the register tones where an operator is able to evaluate visually the spectral characteristics, the tone evenness, a tendency of tone balance in a register and the out-of-tendency tones (an example see in Fig. 2). The recorded samples as well as the analysis results can be saved (automatically or manually) in the format suitable for the archiving and subsequent use.

The operator can export the aggregate acoustical organ documentation into the complex data repository which serves for storing various organ data and the recordings of individual pipe sound. Collected data taken at different times can be used off-line to identify the organ sound changes due to instrument wear, the quality or restoration work, etc.

#### 5. ROOM ACOUSTICS MEASUREMENT

The process applied for the objective acoustic documentation of pipe organ also allows the measurement of room reverberation time based on the analysis of recorded organ tones decay (the organ tone room acoustics method). This procedure does not require any other expensive electronic equipment for the room acoustics measurement. The room acoustic properties with the pipe organ as a sound source are assessed with regard to the organ position in the space and thus can give more credible results than traditional methods with the artificial sound sources, which usually have a position outside of an organ pipe placing. Fig. 4 shows graphs of the recorded sound pressure time course in octave bands 125 – 4 000 Hz with calculated reverberation times T20 and T30 for respective octave bands and total reverberation times T20Mid a T30Mid.

The comparison of room reverberation times T20Mid and T30Mid obtained using a loudspeaker (ISO 3382-1 method) and using the organ pipes (organ tone method) at selected locations shows differences of a few percent. From practice, the comparisons of the octave band reverberation times T20 and T30 also show differences of a few percent, except the band 4 000 Hz where the values are usually lower by 20 – 30 % for organ tone method (the ISO 3382-1 method with a loudspeaker outside of pipe locations poorly express the sound absorption and diffraction caused by the pipe bodies surrounding a sounding pipe).

#### 6. CONCLUSION

The *Inton* system was developed and tested at Musical Acoustics Research Centre (MARC) of Academy of Performing

Arts in Prague and it is currently used by the cooperating institutions for the pipe organ acoustical documentation and for the creation of the database of historical organs in the Czech Republic.

The Inton system available in various configurations gives the advanced methods of pipe organ acoustical analysis not only to highly qualified researchers in acoustics but also to conservationists and organ builders in the organ restoration or building processes, or to musicologists and other users requiring a tool for the objective analysis or comparison of pipe organ sound.

#### **ACKNOWLEDGMENTS**

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