Concepts and Realization of Acoustical Tomography

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Introduction

Tomographic techniques are powerful tools for obtaining insight into physical or chemical properties of areas and volumes. There is also a trend to develop these procedures for non-stationary conditions. We present the realisation of a prototype version of a tomographic system for industrial and scientific applications. It includes conceptual work on several levels. Firstly, the hardware of the system should consist, as far as possible, of an existing product - a multi-channel system with active output. The hardware solution can be applied under a variety of conditions (scalable areas/volumes, adaptive frequencies appropriate to the target and to the physical problem, resilience to background noise etc.). Secondly, a general software concept (including several layers of real-time and near-real-time algorithms, inversion techniques and the user interfaces) is applied to the tomographic system. MATLAB toolboxes for control, algorithms and presentation form the core of the numerical tomography concept. A peculiarity of the travel time tomography of sound waves in fluid media is the dependence of effective sound speed c_{eff} in the medium on a scalar (temperature) and on a vector (v:velocity of the fluid) quantity which must be separated by means of suitable algorithms. The algorithms will be discussed elsewhere:

$$c_{\text{eff}}\left(T_{\text{av}}, v\right) = c_L\left(T_{\text{av}}\right) \cdot n + v \tag{1}$$

where n is the unit vector in the direction of the sound wave. T_{av} describes the acoustical virtual temperature along the path. The separated travel times τ_i that can be calculated from the Laplace sound speed carry the information of the sound speed as a path integral of the form

$$\tau_i = \int_{\text{ray } i} \frac{l_i}{c_{\text{L}}\left(l_i\right)} \tag{2}$$

where l_i are the path elements and $c_{\text{L}}\left(l_i\right)$ are the local Laplace sound velocities.

Measuring System

The tomograph (which is identical for all factors of scaling) is based on acoustic analysers/spectrometers belonging to the *HARMONIE* family (4-, 8-channel units which can be cascaded) or of MSX16 units (16 ... 128 channels) manufactured by SINUS Messtechnik. Our generalised MATLAB interface forms the core of the technological concept for the realisation of the software concept which aims in the provision of a reliable, stable basis for applications programming with a high degree of operating system, driver and hardware independence, reusability, simplified data handling and scalability. It is of importance that the hardware and the software interface is still completely usable for standard tasks in acoustic engineering. The electronic hardware and the modular software packages impose no significant limitations with respect to the flexibility (e.g. number of channels, the geometric extension and more) which is demonstrated for a variety of applications from areas of 1 m^2 (educational and development model (see paper [5]) up to about 500 m x 500 m (large scale meteorological applications).

A generalised structure of the modules and the links within the tomographic system is given in figure 1.

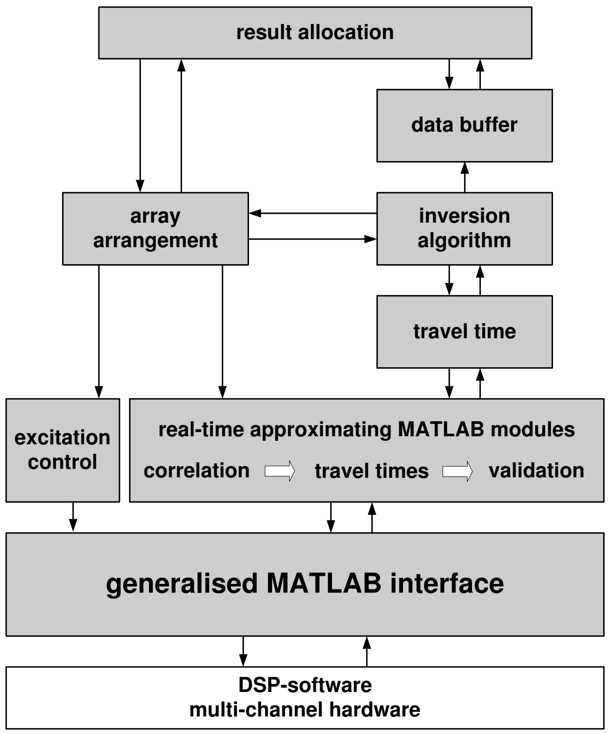

Figure 1: A generalised structure of the modules and their linkings within the tomographic system.

The modules are generally scalable. The hardware-/DSP-systems, which are used for the excitation and data acquisition, can be easily extended to a larger number of channels if necessary. Even a replacement of the hardware does not require a re-writing of code. A crucial technique is the validation of the travel time τ_i estimation (τ_i is the final input parameter for the tomographic imaging algorithm. Some pre-processing steps must be carried out in order to get the correct information from the correlation times and in order to minimise the influence of reflections and of environmental noise. Numerically unusable travel times as input parameters should be automatically avoided as far as possible.

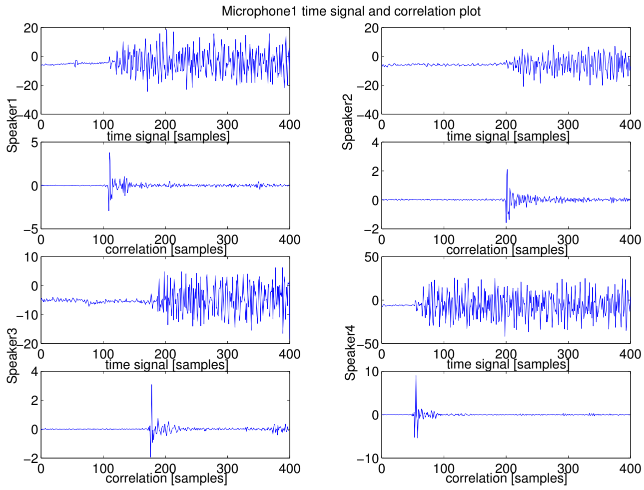

Figure 2: Example of data acquisition at one microphone position. The figure shows the signals of the individual speakers and their according correlations from which the travel times can be estimated

It will be demonstrated that the concept can be applied to tomographic problems of various sizes. Examples are mentioned which demonstrate the scalability of the concept. Small-scale model-size experiments and indoor climate investigation (for a sports hall) have been done. It is intended to use the tomographic system for educational purposes as well as for the training, preparation and realisation phases of expensive measurement campaigns. Theoretical background and specific technical questions are described elsewhere [1]. The intention of this short note is to emphasise the meaning of a highly developed modular approach for an acoustic travel time system which can be used in the audio-range and which is suitable to be adapted to different possible situations (scalability !). Exemplified data made with the model tomograph are given in the paper of Barth et.al. [5]. A further application is the investigation of indoor climate in (sports) halls where temperature and air flow field inhomogeneities greatly influence comfort and usability.

Conclusion

It has been argumented that the realisation of a complex tomographic system is strongly influenced by the modularity of the hardware concept and a consistent software technology concept. A key role plays the general MATLAB layer which interfaces various multi-channel systems with the requirements of tomographic applications. It has been shown that the travel time tomography in the audible frequency range can be adopted to a variety of technical and physical targets which greatly extends the original field of applications in the meteorological sciences.

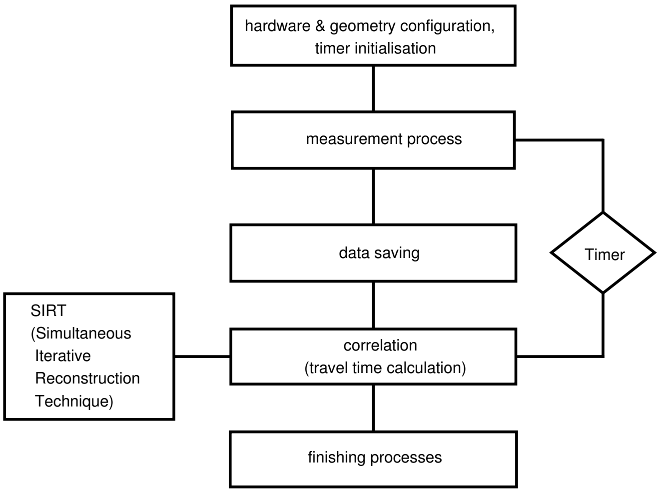

Figure 3: Simplified program structure

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[6] For more information on the multi-channel acoustical spectrometer hardware see URL:
http://www.sinusmess.de/produkte/matlabtb.htm
http://www.sinusmess.de/produkte/harmonie.htm
http://www.sinusmess.de/produkte/msx.htm