An Educational Model for Acoustic Tomographic Imaging

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Introduction and Motivation

The speed of sound in air mainly depends on the prevailing temperature and wind conditions along the propagation path. Consequently, the travel time of an acoustical signal between a sound source and a receiver whose positions are exactly known is a measure of the mean properties along the sound ray path. The remote sensing capability of acoustical sound waves is one reason for their application as a tool to investigate temperature and wind distributions within a certain measuring site in the field of meteorology [1], [2]. Several sound sources and receivers are arranged in a way that the measuring field is covered as homogeneously as possible by sound rays. A set of measured data consisting of travel time values along different propagation paths serves as input for a tomographic inversion algorithm.
With the increase of computational power the use of tomographic reconstruction procedures has become an interesting tool in different fields, such as medicine, geophysics, oceanography and others. In order to introduce students to tomographic techniques using the dependency of acoustical sound propagation in air on the temperature and wind along the sound ray path, an educational model for tomographic imaging has been built. In addition this tomograph can be used to test new hardware and software modules as well as to prepare expensive free field campaigns.

Measuring System

The measuring system consists of a set of acoustical sources (speaker) and receivers (microphones) (see Figure 1) connected to an acoustical spectrometer card which enables to control the whole experiment in connection to a PC (emission, reception).

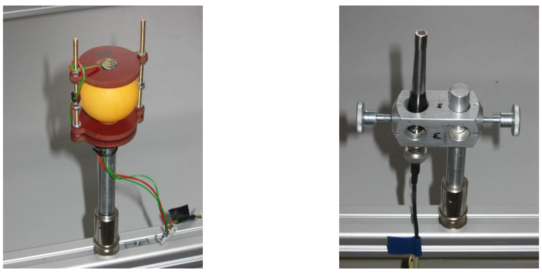

Figure 1: Left: speaker used within the model tomograph with a nearly horizontally homogeneous sound emission. Right: condenser measurement microphone (1/4'').

The software for the control of the hardware as well as for the data pre- and postprocessing (signal generation, cross-correlation to estimate the travel time, tomographic reconstruction) has been developed in a very modular way. Consequently, single program modules can easily be adjusted to special problems and new software modules can be tested.

User Interface

The system can be operated by script-based configuration and execution as well as by an easy-to-handle Graphic User Interface as can be seen in Figure 2.

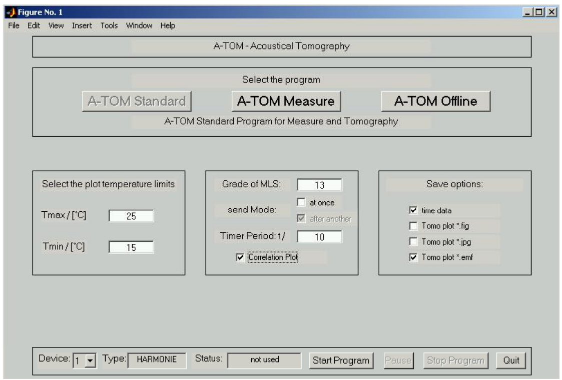

Figure 2: Graphic User Interface (GUI) for the tomographic system to adjust the main settings.

This interface allows the user to adjust the main parameters of the tomgraphic measuring and reconstruction system such as the temperature interval for plotting (Tmax, Tmin), the properties of the acoustical signal (length and emission mode), and repeat rates of the single travel time measurements. Furthermore the user can decide which values should be saved for future analyses. Other settings, such as source and receiver positions, input and output gain or the size of the tomographic grid can be easily adjusted in a configuration file.

Acoustical Spectrometer Hardware

The core of the scalable tomography model is an acoustical spectrometer which is available as a PCI card (for the use in a PC) or as a PCMCIA version [3]. This hardware enables a chronologically-synchronised emission and reception of acoustical signals as required for the certain estimation of the travel times between sources and receivers which serve as input parameters for the tomographic reconstruction of temperature fields.

Sound Signals

In order to obtain the travel times on the different propagation paths a cross-correlation function between the emitted and the received signal is calculated. The location of the maximum indicates the temporal lag between the signal transmission and reception and consequently it represents the travel time of the signal. To indicate the maximum properly an excitation pattern should be used which is well defined (clearly distinguishable from ambient noise) and whose auto-correlation function is characterised by one narrow peak as possible.

Pseudo-random sequences, such as MLS (Maximum Length Sequence), are characterised by an auto-correlation function which is essentially an impulse [4]. Furthermore, such pseudo-random sequences allow to obtain high gain even if only moderate excitation levels are used. As seen in Figure 3 the cross-correlation function of the emitted and received signal differs from an ideal impulse. This is due to the properties of the acoustical system (transfer function, speakers, microphones). Nevertheless, the peak is clearly distinguishable from the ambient noise.

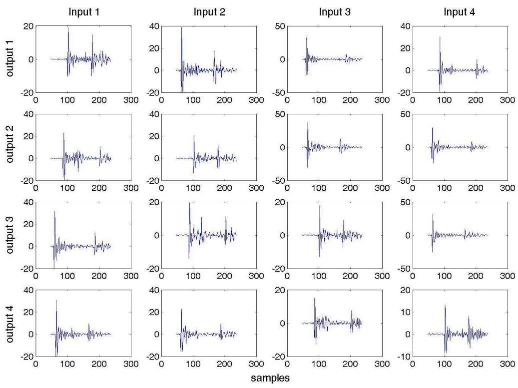

Figure 3: Cross-correlation function between the 4 input channels and the 4 output channels each of which supplies 2 single sound sources. The location of the maxima indicates the travel time for the corresponding sound ray paths.

Model Settings

The flexible model design allows the easy adjustment of a variety of physical measurement parameters, such as the source and receiver positions. This flexibility in modifying the area of investigation is achieved using a frame construction consisting of aluminium profiles. In the laboratory the size of the model extends to 1.23m x 1.23m but this is no restriction in general.

An expansion to larger dimensions with the same measuring equipment (speakers and microphones mounted on tripods) was tested in a hall (reconstructed area: 13.5m x 20m - not shown here). Figure 4 illustrates an example model arrangement with 8 sources and 4 receivers in the laboratory.

Example Tomographic Measurement

An example of a reconstructed temperature distribution as it can be obtained using the laboratory tomographic arrangement is shown in Figure 5. The grid size for the tomographic reconstruction of the temperature field is fixed at 0.25m. In order to obtain a nonuniform but known temperature distribution within the area that can be shown after the tomographic reconstruction, a heating source was placed at the position indicated by the grey-shaded area in Figure 4.

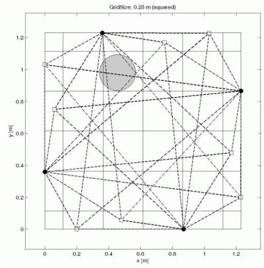

Figure 4: Example tomographic arrangement with 8 sources (open squares) and 4 receivers (filled circles). Dashed lines indicate the sound ray paths, the shaded area (grey) the location of a heating source to produce temperature differences within the measuring field.

In spite of the comparably small sound path lengths, which limit the accuracy of the travel time estimation, and consequently the accuracy of the sound speed (temperature uncertainty of about 0.5K for sound path lengths of 1 m), the temperature distribution is resolved by the tomographic inversion algorithm.

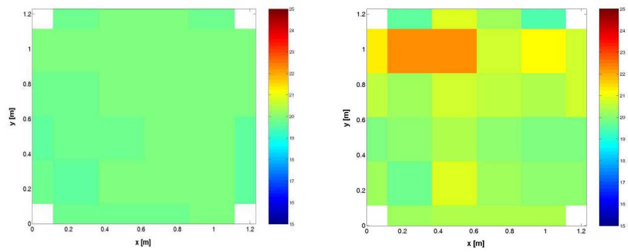

Figure 5: Example tomograms for the laboratory model arrangement as shown in Figure 4. Left: beginning of the measurement: no heating; Right: during the heating period.

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References

[1] Wilson, D.K., D.W. Thomson: Acoustic Tomographic Monitoring of the Atmospheric Surface Layer. *J. Atm. Ocean. Techn.* **11** (1994), 751-769.

[2] Tetzlaff, G., K. Arnold, A. Raabe, A. Ziemann, 2002: Observations of area averaged near-surface wind- and temperature fields in real terrain using acoustic travel time tomography. *Meteorol. Z.* **11** (2002), 273-283.

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

[4] Finger, A.: Pseudorandom-Signalverarbeitung. Teubner, Stuttgart, 1997.