Research Article

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Maciej Szczodrak*, Andrzej Czyżewski, Józef Kotus, and Bożena Kostek

Frequently updated noise threat maps created with use of supercomputing grid

Abstract: An innovative supercomputing grid services devoted to noise threat evaluation were presented. The services described in this paper concern two issues, first is related to the noise mapping, while the second one focuses on assessment of the noise dose and its influence on the human hearing system. The discussed services were developed within the PL-Grid Plus Infrastructure which accumulates Polish academic supercomputer centers. Selected experimental results achieved by the usage of the services proposed were presented. The assessment of the environmental noise threats includes creation of the noise maps using either offline or online data, acquired through a grid of the monitoring stations. A concept of estimation of the source model parameters based on the measured sound level for the purpose of creating frequently updated noise maps was presented. Connecting the noise mapping grid service with a distributed sensor network enables to automatically update noise maps for a specified time period. Moreover, a unique attribute of the developed software is the estimation of the auditory effects evoked by the exposure to noise. The estimation method uses a modified psychoacoustic model of hearing and is based on the calculated noise level values and on the given exposure period. Potential use scenarios of the grid services for research or educational purpose were introduced. Presentation of the results of predicted hearing threshold shift caused by exposure to excessive noise can raise the public awareness of the noise threats.

1 Introduction

Today, in an urban environment, noise is the omnipresent factor that may cause injurious effects to the human health [5]. Exposition to high noise level can seriously affect hearing system, including irrecoverable destruction of the sensitive structures in the inner ear [2]. Recent studies were aimed to assess the threat and to investigate how various diseases are correlated to the environmental or occupational noise exposure [8], [9], [15], [14], [12], [4]. Legal regulations were issued in order to avoid, prevent or reduce the harmful effects of exposure to noise. The European Parliament and Council adopted Directive 2002/49/EC which relates to assessment and management of environmental noise. This legislation requires the authorities of European cities to prepare strategic noise maps for revealing the number of exposed people to noise. In the agglomerations many inhabitants live near the noise sources such as roads or railways. The strategic noise maps provide the long-term averaged noise indicators, determined over all the correspondent periods (days, evenings, nights) of a year, and are often based on averaged or extrapolated data. The proposed approach allows for frequent updates of large area noise maps using the data incoming from road traffic sensors. Moreover, calculated noise level can be verified by measurement of sound level using acoustic sensors. The exposition to an excessive sound level is related to risk of hearing impairment. This concerns both environmental and occupational

*Corresponding Author: Maciej Szczodrak: Multimedia Systems Department, Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology ul. Narutowicza 11/12, 80-233 Gdansk, Poland,
Academic Computer Center, Gdansk University of Technology, ul. Narutowicza 11/12, 80-233 Gdansk, Poland
E-mail: szczodry@sound.eti.pg.gda.pl
Andrzej Czyżewski: Multimedia Systems Department, Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology ul. Narutowicza 11/12, 80-233 Gdansk, Poland
Józef Kotus: Multimedia Systems Department, Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology ul. Narutowicza 11/12, 80-233 Gdansk, Poland
Academic Computer Center, Gdansk University of Technology, ul. Narutowicza 11/12, 80-233 Gdansk, Poland

Bożena Kostek: Audio Acoustics Laboratory, Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology ul. Narutowicza 11/12, 80-233 Gdansk, Poland
Academic Computer Center, Gdansk University of Technology, ul. Narutowicza 11/12, 80-233 Gdansk, Poland

noise. Common access to audio equipment, such as personal music players, and various types of entertainment could create a hidden health hazard for their users [3], [6]. The exposure to excessive sound level, both in form of urban noise and loud music, results in a temporary shift of the auditory threshold. Therefore, software for estimation of auditory effects, which are caused by the exposure to excessive noise, was proposed and developed as a part of the mentioned supercomputing grid services.

2 Methods

2.1 The concept of calculation of noise maps on the supercomputer

The noise mapping service computational model is based on the Harmonoise methods provided for source and propagation [13], [16]. The propagation method describes the attenuation between each pair of the point source and the receiver. The model uses a concept of the sound propagation paths representing the schematic, straight-line tracks of the sound waves between source and receiver points. The short-term, equivalent sound pressure level $L_{Eq1h,i}$, at frequency i, at a certain receiver position, is calculated by summation over a number of contributions from N propagation paths as shown in Eq. 1.

$$L_{Eq1h,i} = 10 \, log \sum_{n=1}^{N} 10^{L_{Eq1h,i,n}/10} \qquad (1)$$

Each propagation path contribution regards the sound power of source and the attenuation of sound between the source and the receiver. A general formula is described by Eq. 2.

$$L_{Eq1h,i,n} = L_{W,i} - A_{div} - A_{atm,i} - A_{refl,i} - A_{sc,i} - A_{E,i} \quad (2)$$

where:

$L_{W,i}$ – sound power level of source,
A_{div} – the attenuation due to geometrical spreading,
$A_{atm,i}$ – the attenuation due to atmospheric absorption,
$A_{refl,i}$ – the attenuation due to energy loss during reflection,
$A_{sc,i}$ – the attenuation due to scattering,
A_E – excess attenuation due to ground reflections and diffraction effects,
i – frequency index.

The source model implemented in the noise mapping grid service is designed to work with various types of noise source. At present, these are roads, railway and point source. In case of linear sources, the model consists of vehicle description and traffic characteristics. The sound power of a single vehicle is calculated on the basis of velocity as one of the input parameters. The traffic characteristics is utilized to combine noise emission of numerous single vehicles according to traffic statistics. The output of the source model is the sound power per one meter length of linear source. In the case of the point source, the model includes the precise source directivity which can be provided for each of 1/3 octave band frequency separately. The algorithm of noise mapping is optimized for working on supercomputing clusters, because the complexity of computational procedures of acoustic field modeling is high [1], [17]. Moreover, the concept of dynamic noise map assumes that acoustic disturbance in the urban area is determined and presented in some short time periods. Contrary to the common approach in popular noise mapping software based on dividing the computation area into subsegments and then processing the portions, parallelization is different in the described algorithm. In our method each receiver point is calculated separately and the outcome is sent back to the main procedure. A master-slave parallel programming paradigm was applied in connection with the MPI programming standard. Small granularity of data leads to maintain a proper load balance of the processors. The sound propagation paths are obtained by employing the acoustic ray tracing method [18]. A set of rays is sent from each receiver point. The algorithm detects collision of the ray with barriers (i.e. buildings) or sources. The next step determines the geometrical cross-sections, representing paths along which acoustical energy is transmitted from source point to receiver point. Total sound level at each receiver is calculated according to Eq. 1.

2.2 Distributed measurement system as a source of noise map updates

The discussed grid service introduces a new feature which is called dynamic noise map. The algorithm is designed to create noise maps updated more frequently than the strategic noise maps. Contrarily to the strategic noise maps which base on averaged and not up-to-date source data, the presented service acquires parameters characterizing the source model coming from continuous measurements. The proposed concept is aimed to gather non-acoustical parameters of noise source such as traffic volume from the sensors located near roads. Measurement devices offer also outcomes of sound level. This significant improve-

ment of data acquisition allows keeping up-to-date short-term noise maps. The diagram of the measurement system connection with the noise mapping service is presented in Fig. 1.

The noise maps can be updated based on either measured traffic parameters or sound level depending on the capabilities of the measurement stations. In the case when road traffic parameters are available, the cumulative traffic volume and average speed categorized by the vehicle type are supplied to the source model directly. Source emission is recalculated and the noise map is then updated. In the case when the traffic parameters are not available and the measurement station provides noise level outcome, the traffic data are re-estimated. This can be done under the assumption that the investigated road provides a main contribution to the measured sound level. The reverse model is applied for this purpose, the detailed description of which is provided in our earlier work [19].

2.3 Use of noise level data for estimation of auditory effects

One of the outperforming function provided by the discussed supercomputing grid services is an evaluation of the auditory effects caused by exposure to excessive noise. The function is realized by the Psychoacoustical Noise Dosimeter, using a modified psychoacoustic model of hearing [11]. Hitherto, the noise dose was determined based on the aggregated acoustic energy that a person experiences in a certain acoustic environment. The proposed method constitutes a different approach, while it concentrates on the prediction of hearing fatigue that a person incurs due to the presence of specific noise. The method takes into account the processes occurring in the inner ear. In the proposed solution, the modified Johnston's psychoacoustic model is used [7]. The starting point is transferring the noise signal into frequency domain using the Fast Fourier Transform (FFT). Then, the spectrum coefficients are conditioned by the outer to the inner ear transfer function and grouped into critical bands using Bark scale. Next, signal levels in particular bands are determined, and the result reflects the excitation of the basilar membrane within the cochlea. The instantaneous values are the input data of the Asymptotic Threshold Shift (ATS) modeling. It consists of three connected parts, local time averaging, global averaging and structural parts of the TTS effect decay. The model is thoroughly described in our previous work [10]. The role of the dosimeter is to estimate, in quasi-real time, the auditory effects evoked by exposure to the noise. The parameters of the dosimeter concern de-

tailed conditions of exposure to noise such as noise level, exposure time and energy distribution in the frequency domain. The outcomes are presented in form of a cumulative noise dose and characteristics of temporary threshold shift (TTS) of hearing. The input data for the noise dosimeter may be provided in various forms. The first one is sound recording for the considered acoustic and exposure conditions. The second type of data is a matrix containing immission noise in 1/3 octave bands for a set of points, calculated by the noise mapping service described in section 2.1. This yields a map of TTS, similar to the noise map, corresponding to the defined exposure period.

3 Sample scenarios

The noise threat evaluation employing supercomputing grid services can be used in various scenarios. In this section we present two chosen use cases. The first relates to dynamic noise mapping with the use of the data acquired from the sound level measurements. The second shows an example of the evaluation of the threat of excessive sound level caused by the outdoor music concert. In the first scenario, the base noise map is calculated for one year averaged traffic data. The calculation process is two-fold. Sound attenuation for each propagation path between a pair of source and receiver is obtained using the acoustic ray tracing method. Since the computational cost of the latter is high, intermediate data are utilized in further calculations of the noise map when the source parameters change. Traffic parameters are estimated with the use of the reverse model. Then, source emission level is updated and immediately combined with pre-calculated attenuation for each propagation path. In the second scenario, influence on hearing caused by exposition to the excessive sound level over a defined time period is presented in a form of the maximum Temporary Threshold Shift value. TTS is obtained based on the sound level calculated for each receiver. Detailed data for each 1/3 octave band are supplied to the algorithm which evaluates TTS.

4 Simulation results

This section shows the illustrative results of simulations for the scenarios presented in section 3. Location for scenario 1 was chosen in an industrial district of the city within area of about 2.6 × 2.5 kilometers. The prevailing amount of noise in that area is generated by four major roads. Averaged (long term) traffic volume for the day time
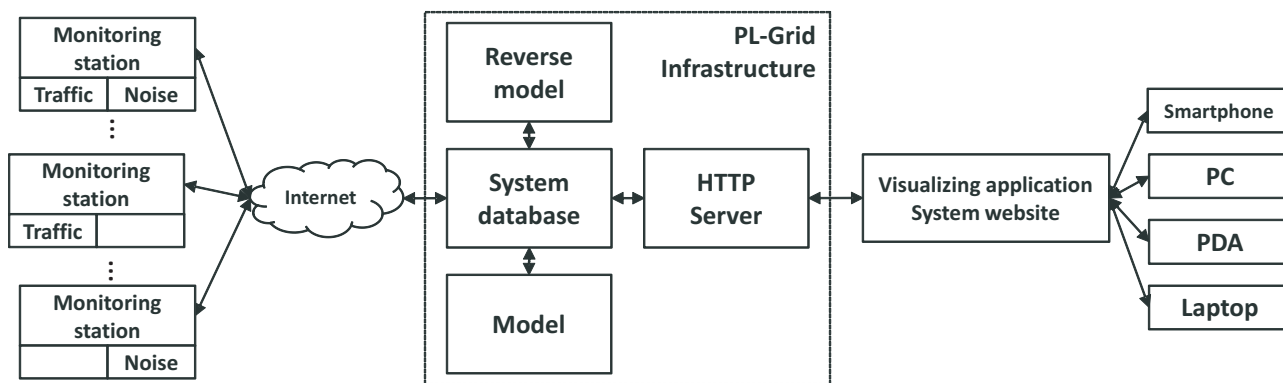
Fig. 1. The distributed measurement system as a source of noise map updates.

on that streets varied between 200 and 936 vehicles per hour. The base noise map was calculated using the average traffic data available for all streets in the considered area. The base noise map is shown in Fig. 2. Moreover, four noise measurement stations (P01–P04) located near main roads provided the detailed sound level data ($L_{AEq,1h}$). The sound level measurements were for week 44, 2013. The comparison of the results for points P01–P04 calculated by the use of the reverse model based on measurement data and the average data is shown in Fig. 3 and Fig. 4. We can observe, that the noise level during day, evening and night period is much higher in case of dynamically updated map, particularly for roads near points P01 and P02. The long term indicators were calculated for traffic data which may be out-dated. The increase of traffic flow in P01 and P02 may originate due to the fact that the traffic was re-organized in nearest area shortly before the measurement results were acquired. In case of P03 and P04 the results of long term and short term noise levels were more convergent. Largest differences were observed for L_N, 12 dB to 18 dB, and the smallest (4 dB to 6 dB) were observed for L_E.

The noise map presented in Fig. 2 consists of 65905 points and was calculated on 96 cores. For each point, when rays were sent with one degree interval, the average number of propagation paths was nearly 2038. The total number of propagation paths was equal to 134,336,217. The achieved calculation speed for base was about 13.5 points per second. The update of the map with the use of pre-calculated propagation paths, run on one core, took in an average about 1020 seconds what gives about 64 points per second. However, the amount of data generated by acoustic ray tracing required to use a cluster node with memory of 32 GB. In order to achieve update period of 1020 seconds without two-stage processing, calculations would have to be conducted on 466 cores each time. For example, 24 updates per day would use 3168 core hours.

Another example relates to creation of maps of outdoor noise comprising auditory effects. We considered the outdoor concert at a city square. The auditory area, limited by surrounding buildings, was about 100 × 130 meters. The stage width was 10 m. The speaker system was modeled as two sources located at both sides of the stage, where each consisted of 3-point sources located at 4.0, 4.1 and 4.2 m. We assumed that no other sound sources apart from loudspeakers exist. Sound level of source in 1/3 octave bands was obtained based on measurements of rock music concert. The directivity of each source was based on characteristics of loudspeakers commonly used during the concerts. The characteristics were given for each of 1/3 octave band frequency. Fig. 5 presents the map of noise produced by loudspeakers and map of the maximum TTS values for three hours of exposition. Fig. 6 presents the change of the maximum TTS value with the distance to the source, starting from 20 m, along section A–A'. The observed TTS exceeding 20 dB extends in radius of about 30 meters from the center of the stage. The hearing recovery time required for the people present in this area was found at approx. 300 minutes maximum. The obtained period is related to 20 dB TTS and would be observed for persons distant about 30 m to the stage. The safe area where the TTS not exceeds the level of about 5 dB begins about 70 meters away of the stage. Time and spectral character of noise play an essential role in TTS changes during exposure [10]. The TTS model is complex, calculation of one point requires several seconds to complete on a single core. The supercomputer advantage is that many points can be calculated simultaneously, what significantly speeds the computation of the TTS map.
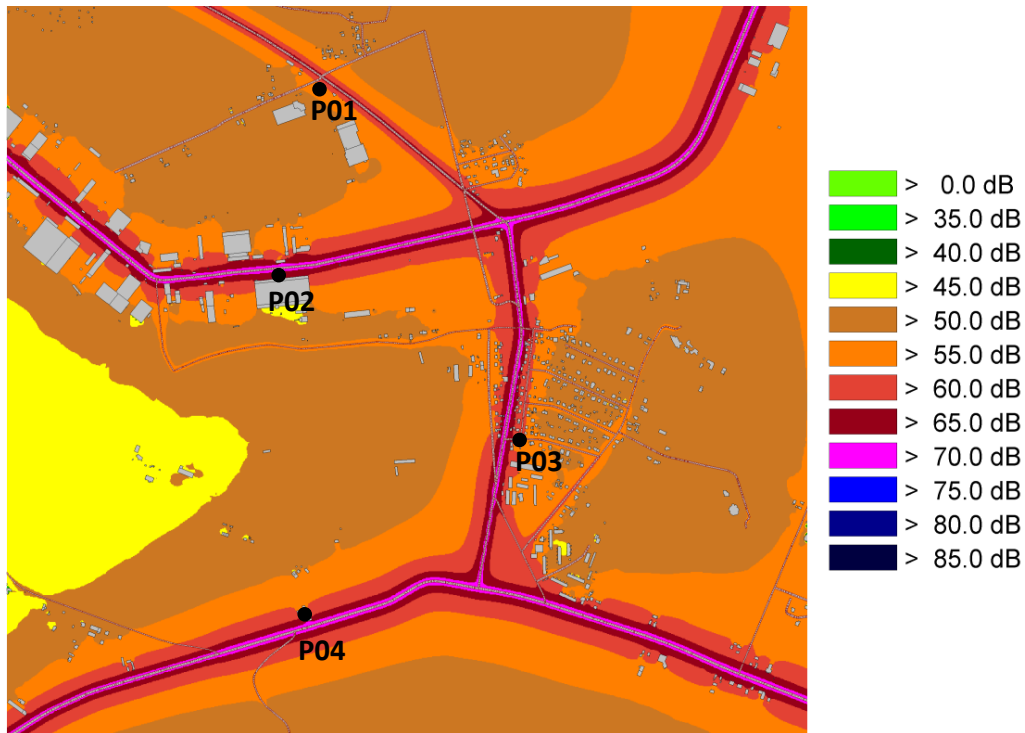
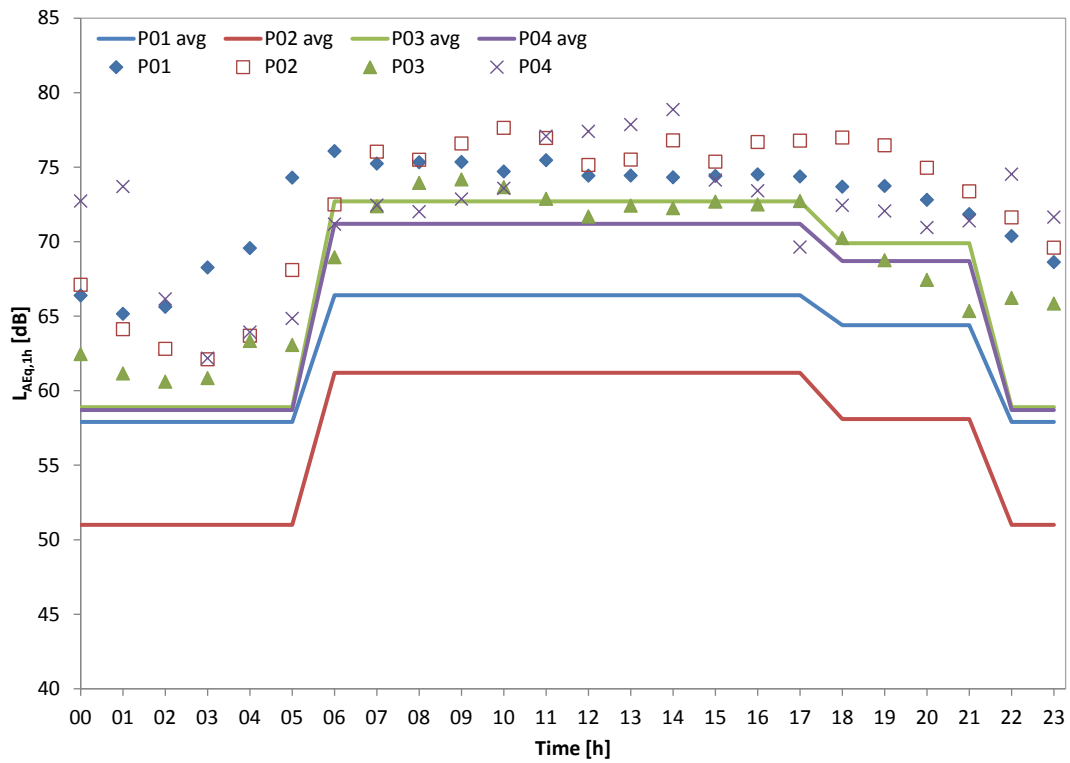**Fig. 2.** Noise map of the area covered by monitoring stations

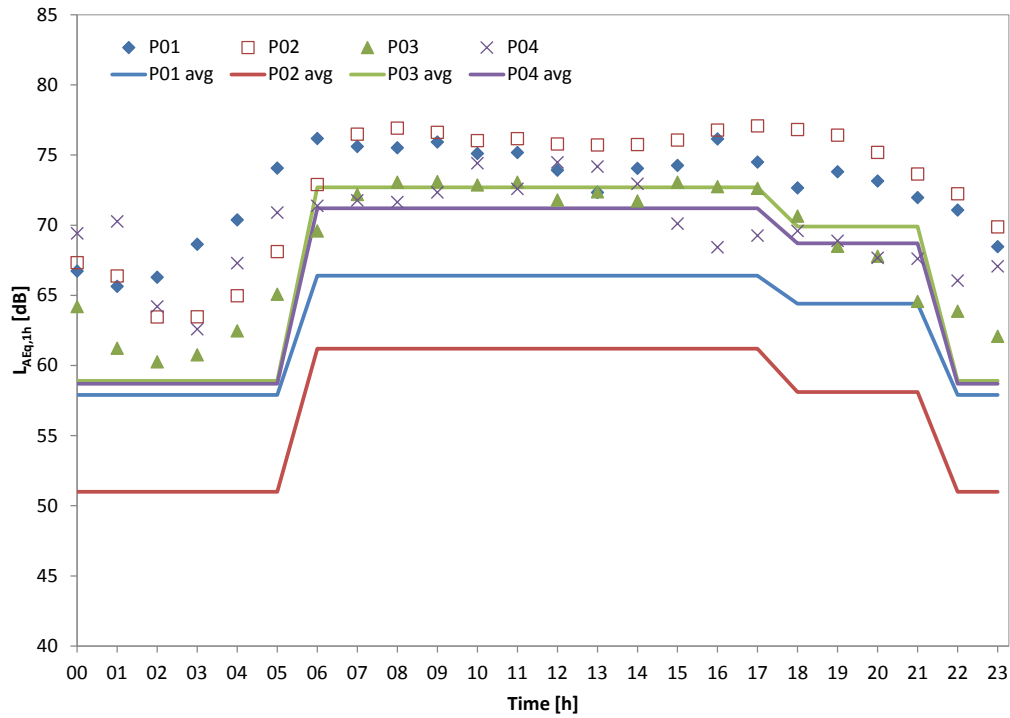**Fig. 3.** Comparison of calculated short term and long term noise level on 2013.10.30

Fig. 4. Comparison of calculated short term and long term noise level on 2013.10.31
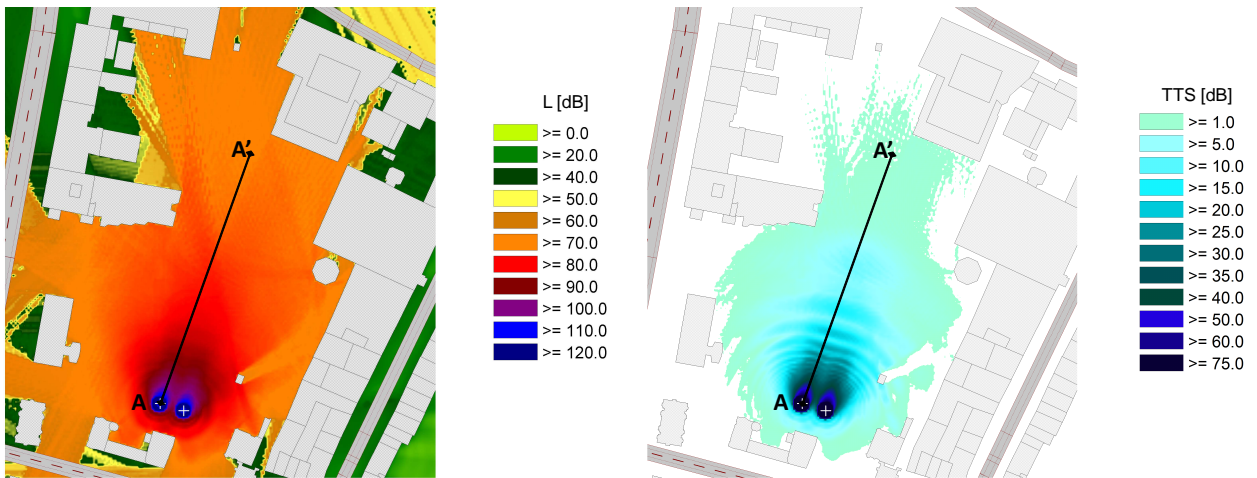

Fig. 5. Sound level distribution outcome of simulation of the concert at the city square (left) and the map of the maximum TTS values that could be evoked (right).
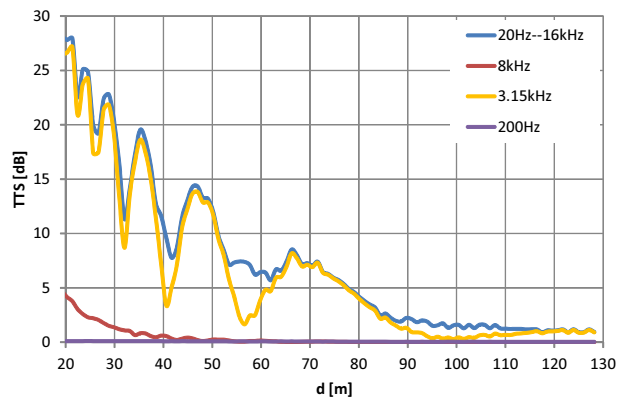
Fig. 6. TTS evoked by considered acoustic conditions at the cross section A-A'.

5 Conclusions

The supercomputing grid services for evaluation of the noise threat were described. Two main functions of the developed tool can be distinguished, namely generation of frequently updated noise maps and evaluation of the influence of the noise on human hearing. The potential of the system for dynamic noise maps update employing supercomputing grid and sensor network was presented. A unique feature of the implemented software is the traffic flow determination on the basis of sound level measurements. The calculated traffic flow data were used to automatically update noise source model. Designing the noise propagation algorithm and optimization for supercomputer cluster usage results in rapid noise map recalculation. The experimental results show that dynamic noise threat maps may constitute the source of precise data about the acoustic climate. The analysis of auditory effects caused by the excessive sound level was preformed. The results were achieved by connecting sound propagation algorithm and psychoacoustical noise dosimeter. Presented sample outcomes of TTS induced by the outdoor concert show practical usefulness of the developed methods. Prediction of the harmful effect that can be evoked by loud music can be useful for hearing protection of the audience. Moreover, availability of the PL-Grid Infrastructure for education and research can lead to the widespread tool for aiding noise abatement.

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