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# THE APPLICATION OF A NOISE MAPPING TOOL DEPLOYED IN GRID INFRASTRUCTURE FOR CREATING NOISE MAPS OF URBAN AREAS

**Abstract** *The concept and implementation of the system for creating dynamic noise maps in PL-Grid infrastructure are presented. The methodology of dynamic acoustical maps creating is introduced. The concept of noise mapping, based on noise source and propagation models, was developed and employed in the system. The details of incorporation of the system to the PL-Grid infrastructure are presented. The results of simulations performed by the system prototype are depicted. The results in the form of noise maps obtained by a system are compared with some other solutions in order to investigate accuracy.*

**Keywords** noise, noise map, noise modeling, grid computing

## 1. Introduction

The threat that environmental noise poses to human health has become an issue of considerable significance, especially in the heavily urbanized areas [1, 2, 3, 4]. This detrimental factor has profound implications on the quality of life but also on public health. In order to assess the threat, the European Parliament and Council issued the legal foundation for undertaking urban noise monitoring in all Member States. In 2002 the European Parliament and Council issued the European Directive 2002/49/EC relating to the assessment and management of environmental noise. The main aim of this Directive is to provide a common basis for tackling the noise problem across the EU [5]. It commits the EC-member states to evaluate the noise impact for all agglomerations, for all major roads and major railways and for all major airports within their territories and to present it on strategic noise maps. Until 30 June 2007 noise maps had to be prepared for all cities – or more precise, for agglomerations – with more than 250,000 inhabitants. Till 30 June 2012 all agglomerations with more than 100,000 inhabitants have to be mapped, too. The commercially available applications deliver full functionality to prepare the noise map, but they work mainly on windows platform. Computation of noise map for large city areas would result in high calculation time [6]. To solve that problem the software to calculate road and railway noise on supercomputer platform was proposed and developed [6, 7, 8]. The procedure for preparing the noise map requires a knowledge of source data and propagation environment. The model for calculating the acoustic field distribution in urban area is based on the acoustic ray tracing method. Considering source models, we need to note that road and railway noise are the most frequent sources of disturbance that people are exposed to. The achievements of European Harmonoise and Imagine projects providing a description of road and railway models were utilized during the implementation of the software engineered by the authors. The Harmonoise model [9, 10] was intended to unify all the methods worked out by European Union state members.

Similar work concerning noise mapping with the use of a computational grid has been accomplished in the GDI-Grid project [11]. The presented approach was based on dividing the calculation area on some smaller tiles and on the parallel processing of tiles. Our method is different because it uses a more sophisticated parallelization technique yielding the proper cluster load balancing. It is provided by the utilization of the MPI standard and finer granularity obtained because the area is broken into single points.

A process of computation of sound level distribution in urban areas, realized by noise map calculation software optimized towards working on a supercomputing cluster, was presented in this paper along with a detailed description in the next Sections. The aim of the work undertaken is to provide efficient computational tools for the community of acousticians engaged in noise threat reduction. The developed software allows also for conducting scientific investigations devoted to verify mathematical models against environmental measurements.

# 2. Description of the problem solving

## 2.1. Noise source and propagation model

The method of creating a noise map is based on mathematical models of noise source and propagation. The source model consists of vehicle and traffic models. The sound power of a single vehicle is calculated on the basis of velocity as one of the input parameters. The traffic model is utilized to combine the 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. The resultant sound level is calculated in defined grid of receiver points using the propagation model. The concept of sound propagation paths describing schematic lines of acoustic wave traverse between a single point source to receiver is utilized in the model. The sound propagation paths are obtained by employing the acoustic ray tracing method [12, 13]. This method is used for investigating sound wave propagation in urban areas. The diagram of ray tracing algorithm is presented in Figure 1. A set of rays is sent from each receiver point. The algorithm detects the collision of the ray with barriers (i.e. buildings) or sources. Then, geometrical cross-sections, representing paths along which acoustical energy is transmitted from source point to receiver point, are determined.

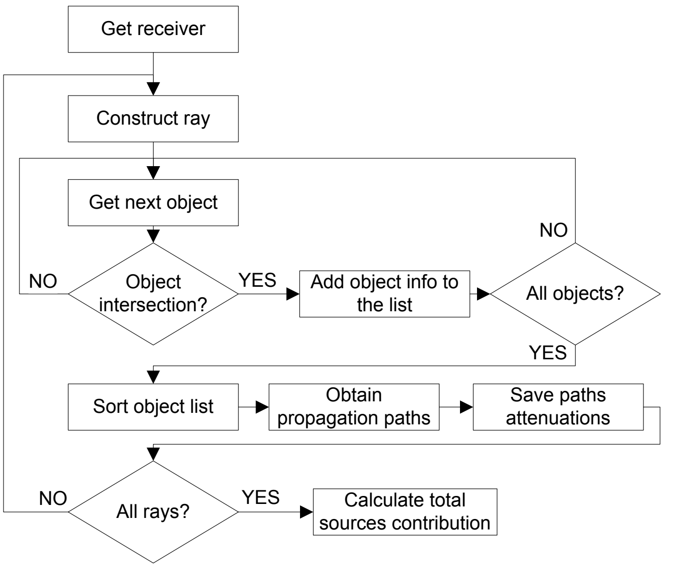


**Figure 1.** Acoustic ray tracing algorithm.

The propagation method [12, 14] describes the attenuation between each pair of point source and the receiver. Point sources are introduced by the segmentation of the linear source which is done by ray tracing. In the real atmosphere a number of factors affects sound propagation, including absorption of sound in air, non-uniformity of the propagation medium due to meteorological conditions, and interaction with an absorbing ground and solid obstacles (such as barriers) [15]. Total sound level in each receiver is obtained by an aggregation of the influences of sources found by ray tracing with respect to calculated values of sound attenuations on the propagation paths.

## 2.2. Parallel implementation of the model

Achieving a tolerable time of computation of dynamic noise maps required implementation of a method for parallel data processing. The applied method of noise modeling has such advantage that the sound level can be estimated in each point of the input grid, independently. The algorithm is presented in Figure 2. The authors developed their own code for the noise prediction model based on open source programming libraries [6, 7, 8]. The main engine of the propagation model includes the implementation of the acoustic ray tracing method. For exploiting the computer cluster capabilities, a master-slave parallel programming paradigm was applied in connection with the MPI programming standard to achieve a proper load balance. The previous version of the Noise Prediction Model software was compiled and utilized within one supercomputer cluster ('Galera+' in CI TASK).

## 2.3. Integration with PL-Grid infrastructure

The software was deployed on selected supercomputers of the PL-Grid infrastructure. The integration of the Noise Prediction Model with the PL-Grid run in two phases and QosCosGrid client software was used as the middleware over the queue systems on clusters [16]. First, the software was compiled on the clusters 'Galera+' and 'Zeus'. The mentioned supercomputers belong to the group of the most powerful machines in Poland, having, respectively, 10 384 and 23 932 cores. On the TOP500 rating of June 2012, 'Zeus' took a high, 89th position and 'Galera+' was on placed 447$^{\text{th}}$ position. Assignment of the task to a physical computational resource (cluster) was determined by the user in the configuration file. For task management, QCG-Broker was employed.

In the second phase, the multi-cluster run scenario was incorporated. In order to achieve the result, a code was build with qcg-ompi libraries. The application was compiled preliminarily on two supercomputer clusters 'Nova' in WCSS (6400 cores) and 'Zeus' in Cyfronet. This approach will allow for more convenient utilizing distributed computational resources while being regarded as one logical cluster. In the prototype version of the PLGrid Plus 'Noise' service, the interface is in form of text console access. The user has to provide the input data by uploading it into the storage. The input data have to be prepared by the user locally with dedicated software. The user specifies the location of the input data in the configuration options of the program. The user manages the computations with the QCG text client. When a calculation process is completed, the user downloads the output data and performs post-processing and visualization on the local terminal. The diagram showing the use of the system is presented in Figure 3.

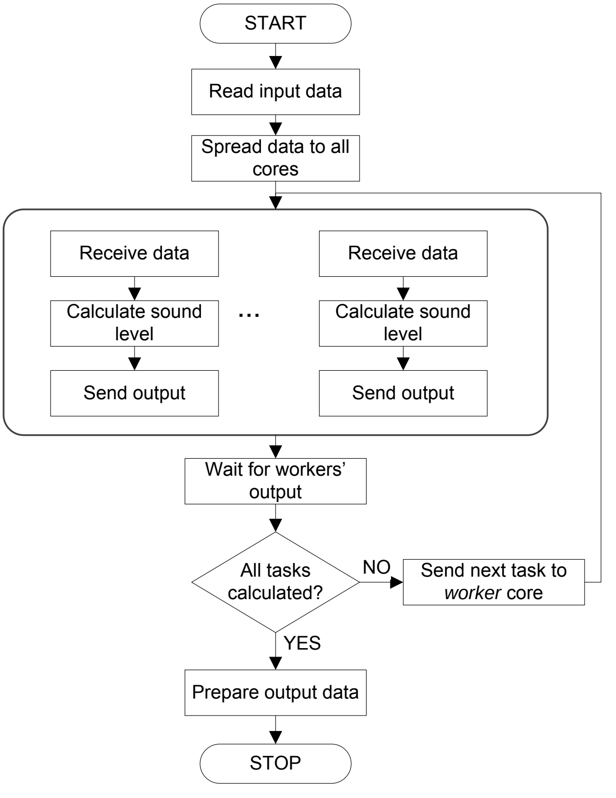


**Figure 2.** Algorithm for creating noise maps.

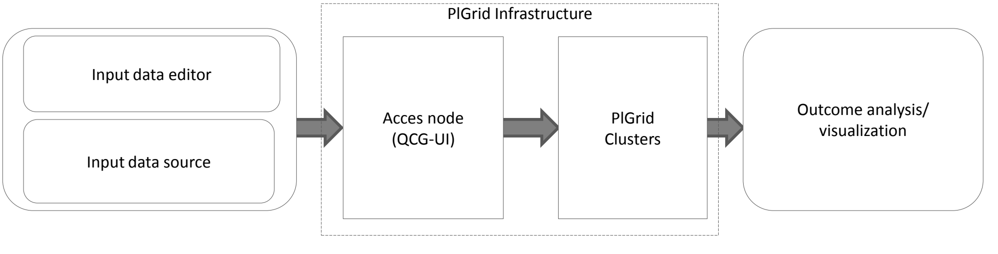


**Figure 3.** Typical workflow in the prototype version of 'Noise' service.

## 3. Results

An illustration of the application of the developed solution is the urban area noise mapping. The fragment of the calculated noise map of Gdansk is presented in Figure 4. Such a map can be completely updated within a relatively short period of time employing the PL-Grid infrastructure. Our previous experiments on a single cluster show that the discussed map can be updated daily [6]. A series of tests of developed application in the PL-Grid infrastructure have been conducted including map accuracy and computation efficiency. The first test case concerns investigation of calculation time for diverse grid size, the second test case shows accuracy of created noise map in comparison to the reference map. The input data for the noise map creation is identical for both test cases. The following main parameters of the propagation model were set: reflections of the 1st order, search ray 2000 meters, reflected ray 100 m, the distance between the following rays 2 degrees, and the building sound reflection coefficient 0.8. The input data consisted of a geometrical description of roads (3639 road segments) and buildings (92 234 buildings), the traffic volume (archive measurements) and the vehicle speed (50 km/h for each vehicle category). All other parameters in the program were set to the default values, i.e. stone mastic asphalt pavement type, uninterrupted traffic flow. The ground type for the whole area was set to 'hard surface' (representing asphalt or concrete). Calculated maps show a sound level $L_{A,Eq}$ averaged for 1 hour.

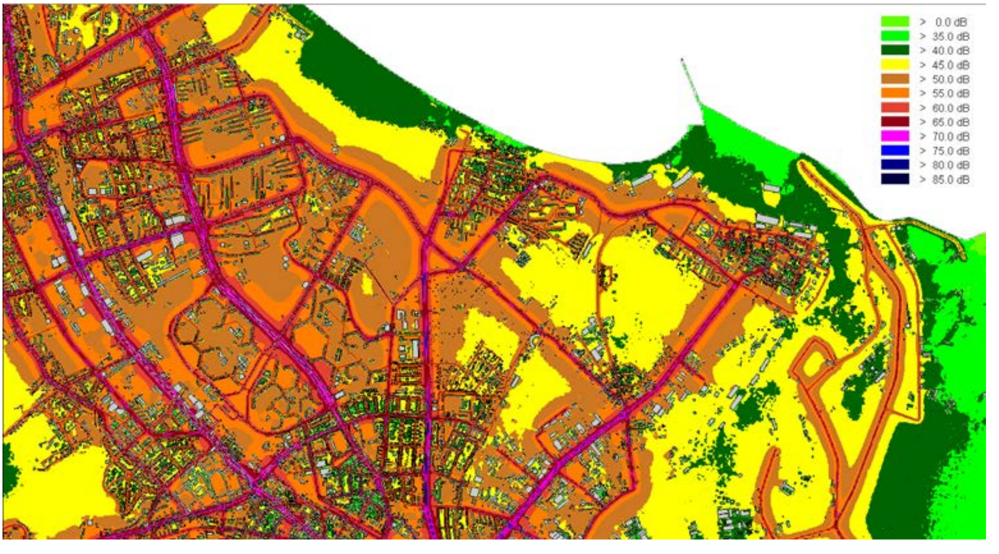


**Figure 4.** The noise map of Gdansk, area shown of 8000×4000 m.

The computation time for the diverse grid size is presented in Table 1. From the point of view of the end user, the denser grid is better. Nevertheless, the numerical cost of creating such map would be very high. Therefore, the comparison of computation time was conducted in order to estimate the reasonable tradeoff between quality and cost. The size of both maps was 256×256 meters. The discussed map represents a fragment of the city centre, where the concentration of infrastructure is very high. The cost of the calculation map for the dense grid is 3.8 to 3.2 times slower than the sparse grid. The graphical illustration of considered outcomes is presented in Figure 5.

The total number of points to calculate is 1024 in the case of grid 8×8 m and 3969 in the case of grid 4×4 m. For each grid, the speedup of the computations value was determined as the ratio of computation time at particular number of engaged cores to computation time at 12 cores. It can be noticed that the reducing the computation time by doubling the number of cores is nearly proportional. In the ideal case, the speedup coefficient should be equal to 2 and 4. An obtained speedup value greater than 4 (see Table 1) is related to the fact that measured computation time differs even if one experiment is repeated in the same conditions.

**Table 1**

Computation time comparison for diverse grid size.

| Number of cores | Grid 8×8 m | | Grid 4×4 m | |
|---|---|---|---|---|
| | Time [s] | Speedup | Time [s] | Speedup |
| 12 | 29 813 | 1 | 113 177 | 1 |
| 24 | 17 882 | 1.67 | 57 390 | 1.97 |
| 48 | 8080 | 3.69 | 27 753 | 4.08 |

The second test embraces a comparison of the outcomes obtained by the developed Noise Prediction Model (NPM) software with the reference data (REF) originating from a commercially available software. In both programs the result was represented as a matrix of noise level values in the specified area.

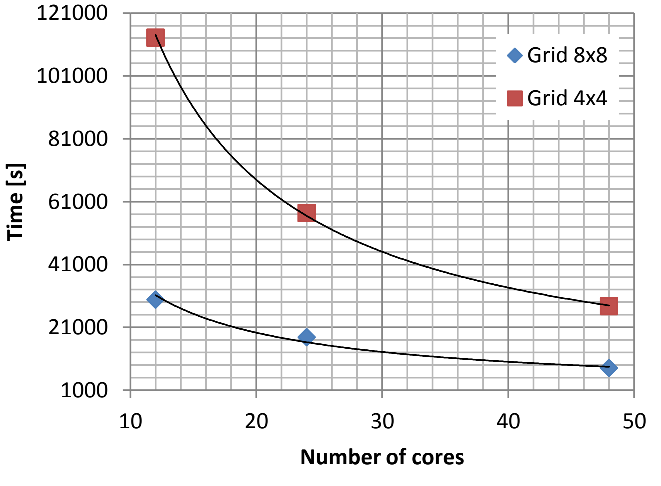


**Figure 5.** Grid size and calculation time dependence of number of cores.

The region of the city considered for comparison is characterized by a mixed urban density. Aside from high buildings and busy streets, some area not covered by infrastructure was found. The graphical representations of the results obtained with the reference software and with the Noise Prediction Model are shown in Figure 6 and Figure 7. The difference map showing the Noise Prediction Model results subtracted from reference software results is presented in Figure 8.

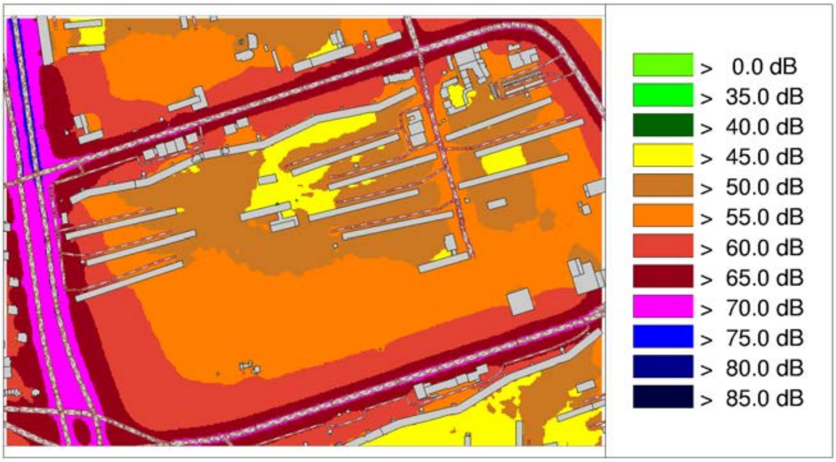


**Figure 6.** Noise map created by reference application (REF).

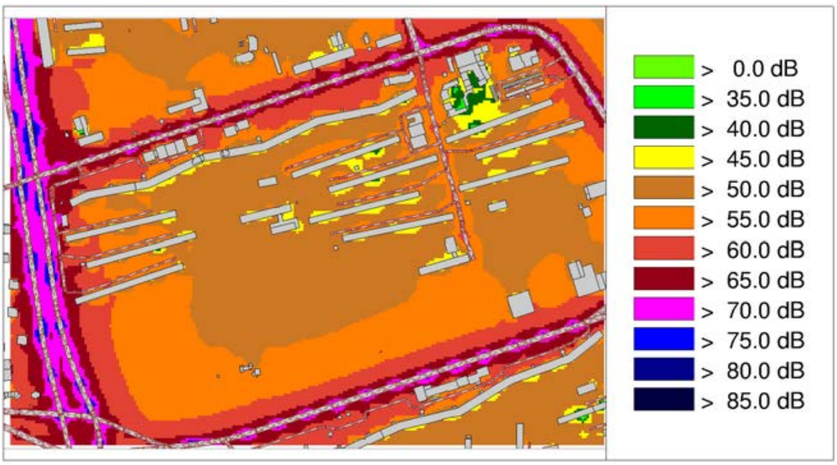


**Figure 7.** Noise map created by NPM application.

The prevailing discrepancies remain within the range of $\pm 1$ dB. High similarity of sound level can be observed in nearly all areas. The differences are noticed in situations of screening by large building aggregations, where NPM gives overestimated values. Other discrepancies can be observed in a free field, where NPM outcomes are underestimated. A clear influence of propagation factors is dominating in this situ-

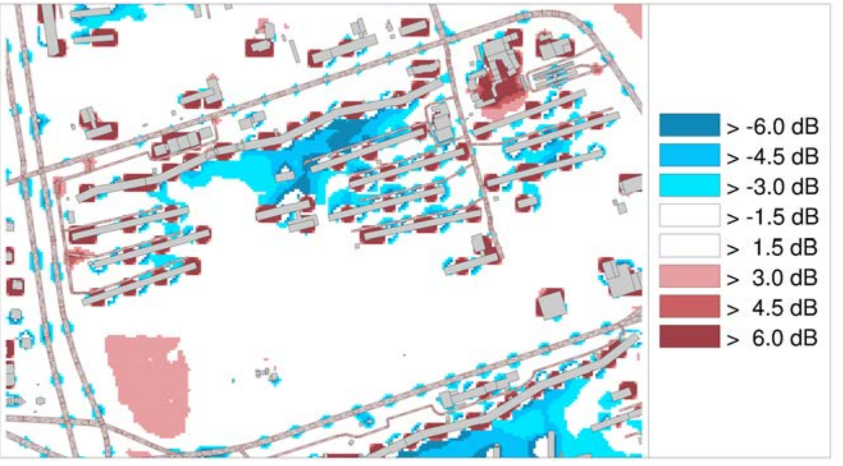


**Figure 8.** Difference map, REF-NPM, hard propagation ground.

ation. The calculated sound level in the terrain near source is nearly the same in the case of both noise mapping programs. Areas distant from the roads show noise level lower as much as about 2–4 dB in the case of the Noise Prediction Model. The difference may originate from various propagation models. Certainly, the ground type parameter is not compatible in NPM and reference software propagation models. The reference software implements ground attenuation model according to the norm ISO 9613, and the Noise Prediction Model uses a more detailed flow resistivity parameter, according to the Harmonoise model. Moreover, the significant difference between software is that NPM operates in 1/3 octave bands and uses a more precise source model, employing 2 or 3 noise sub-sources for each road.

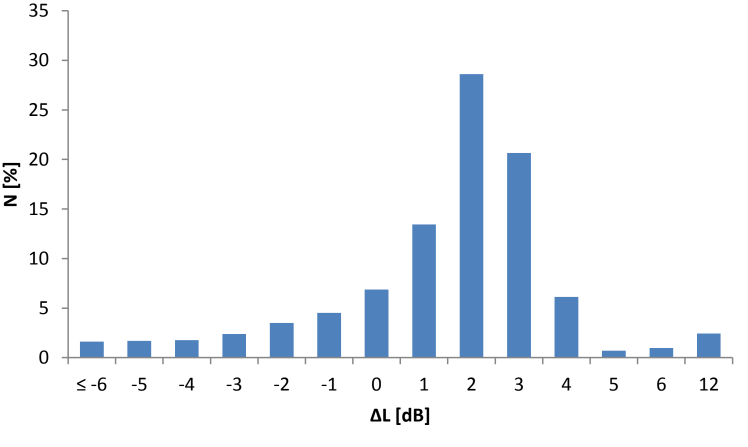


**Figure 9.** Histogram of difference of noise level in case of hard propagation ground.

Error distribution is presented in Figure 9. We can observe that the prevailing value of discrepancies is situated in the range of 1–4 dB. In order to achieve a more desired error distribution, a ground type parameter value in NPM software was changed to 10 000 $\text{kNsm}^{-4}$, what means softer ground (previous value 20 000). The resultant difference map is presented in Figure 10. For this type of surface, the propagation is correct, and we can observe the differences in noise level in areas where high buildings screening influence occur.

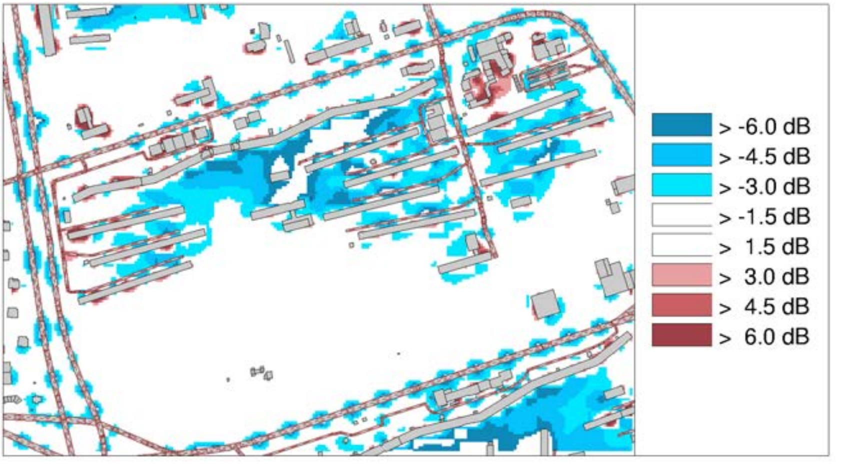


**Figure 10.** Difference map, REF-NPM, softer propagation ground case.

## 4. Conclusions and future work

The concept and results of exploiting the system for creating noise maps with the use of supercomputer clusters were presented. The outcomes of the experiments show that achieving a reasonable computation time of dynamic noise maps is possible. However, the update period in the case of a constant size of the input data is dependent on the area size and available resources. The experiments demonstrate the usefulness of the so-called cloud computing concept employed for environmental noise monitoring and creating acoustic maps in urban areas. The user will be able to run the application on all clusters within PL-Grid infrastructure. The idea is to offer a platform which provides the software for environmental noise modeling together with a sufficient computational power. It can be used by researchers or urban planners for simulating of the noise influence on the environment or for planning new urban infrastructures. Achieving of high computational power is difficult in current configuration of queue systems. It takes long time to wait for running computational tasks in queue systems. Some queue systems have limits in maximum allowed number of cores for one task. We believe that some queue system priorities and limits would be changed. The experience was gathered from users who have tested the prototype service. They mainly express request for more convenient access to the developed noise mapping tool. Therefore, the future work will focus on preparing and implementing a graphical user interface. Moreover, the efforts aimed for running the developed service with Unicore system were undertaken. In the future the noise map could be calculated engaging the large scale computational power of other supercomputers connected in the PL-Grid infrastructure. The possibility of showing TTS induced by traffic noise [17, 18] as an extra layer may be an additional advantage of the presented system.

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## References

[1] Engel Z., Zawieska W.: The State of Protection Against Noise in the Environment in the Year of Poland's Accession to the European Union. In *13th International Conf. on Noise Control*, 2004.

[2] Kompala J., Lipowczan A.: Noise hazard to the population of areas connected with functioning of roadway frontier crossings. *Archives of Acoustics*, 32(2):279–286, 2007.

[3] Kucharski R.: Complex noise indicator for noise mapping based on the EU working groups' and Polish results of the annoyance investigations. *Archives of Acoustics*, 32(2):273–302, 2007.

[4] Popescu D. I., Moholea I. F.: Monitoring the reaction and response of people to urban noise. *Archives of Acoustics*, 35(2):237–244, 2010.

[5] Directive 2002/49/EC of the European Parliament and of the Council. Official Journal of the European Communities, June 2002.

[6] Szczodrak M., Czyzewski A.: Software for calculation of noise maps implemented on the supercomputer. *Task Quarterly*, 13(4):363–377, 2009.

[7] Czyzewski A., Szczodrak M., Kotus J.: Creating acoustic maps employing supercomputing cluster. *Archives of Acoustics*, 36(2):1–24, 2011.

[8] Czyzewski A., Kotus J., Szczodrak M.: Online urban acoustic noise monitoring system. *Noise Control Eng. J.*, 60(1):69–84, 2012.

[9] Nota R., et al.: Harmonoise WP 3 Engineering method for road traffic and railway noise after validation and fine-tuning. Harmonoise Technical Report, 2005.

[10] Maercke, Van D., Defrance J.: Development of an Analytical Model for Outdoor Sound Propagation Within the Harmonoise Project. *Acta Acustica united with Acustica*, 93(2):201–212, April 2007.

[11] Stapelfeldt H., Siepmann D., Fleuren T.: Automated Workflows in Linux High Performance Grid Computing or Standard Windows Applications. In *39th International Congress on Noise Control Engineering – Inter-Noise 2010, Lisbon*, 2010.

[12] Kulowski A.: A modification of ray-tracing acoustics modeling method in rooms. *Scientific Books of Gdansk University of Technology*, 464:1–117, 1991.

[13] Li K. M., Taherzadeh S., Attenborough K.: An improved ray-tracing algorithm for predicting sound propagation outdoors. *The Journal of the Acoustical Society of America*, 104(4):2077–2083, 1998.

[14] Embleton T. F. W.: Tutorial on sound propagation outdoors. *The Journal of the Acoustical Society of America*, 100(1):31–48, 1996.

[15] Engel Z.: *Environmental protection against vibrations and noise (in Polish)*. PWN, Warsaw, 2001.

[16] Bosak B., Komasa J., Kopta P., Kurowski K., Mamoński M., Piontek T.: New Capabilities in QosCosGrid Middleware for Advanced Job Management, Advance Reservation and Co-allocation of Computing Resources – Quantum Chemistry Application Use Case. In M. Bubak, T. Szepieniec, K. Wiatr, editors, *Building a National Distributed e-Infrastructure–PL-Grid*, vol. 7136 of *Lecture Notes in Computer Science*, pp. 40–55. Springer Berlin Heidelberg, 2012.

[17] Kostek B., Kotus J., Czyzewski A.: Noise monitoring system employing psychoacoustic noise dosimetry. In *AES 47th International Conference on Music Induced Hearing Disorders*, 2012.

[18] Kotus J., Szczodrak M., Czyzewski A., Kostek B.: Distributed system for noise threat evaluation based on psychoacoustic measurements. *Metrology and Measurement Systems*, XIX(2):219–230, 2012.

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