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METHODOLOGY FOR VERIFICATION OF SOFTWARE FOR NOISE ATTENUATION CALCULATION ACCORDING TO ISO 9613-2 STANDARD

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Abstract. *One of the goals of the project "Development of methodologies and means for noise protection of urban areas" is the development of software tools for local noise mappings. For the purposes of software verification, we developed method for testing the software for noise mapping and prediction according to ISO 9613-2 standard. This method tests modeling of all physical effects covered by the standard. The paper presents the proposed tests for noise mapping software verification with reference to mapping results, i.e. sound pressure levels calculated according to ISO 9613-2 standard for the each of proposed tests.*

Key words: *noise mapping, software verification, ISO 9613*

1. INTRODUCTION

For the purpose of urban planning and development of action plans for managing noise issues and effects, it is necessary to produce strategic noise maps. These maps are intended to describe the environmental noise levels and to assess the total number of seriously annoyed residents. In accordance with Environmental Noise Directive (2002/49/EC) [1], noise mapping and drawing of Noise Action Plans became mandatory for major cities of the European Union.

Noise maps can be created on the basis of experimental measurements of noise levels or by applying the appropriate calculation methods. As calculation methods enable prediction of noise levels at large number of receiver points, and also prediction of future noise, they are significantly more used. Software packages for noise mapping are numerous, but their price is usually high. The best-known software packages for noise

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mapping are LIMA Predictor [2], Cadnam [3], IMMI [4], SoundPlan [5], Olive Tree Lab [6], SPM9613 [7].

As Serbia is in the accession process to the European Union, Serbian legislation related to noise protection is in accordance to Environmental Noise Directive. Since there is no commercial software tool for noise mapping at this moment in Serbia, and only representatives of foreign companies offer software solutions, Faculty of Mechanical and Civil Engineering Kraljevo has been developing software tools for local noise mapping in course of the project "Development of methodologies and means for noise protection of urban environment" [8] funded by the Serbian Ministry of Education, Science and Technological Development.

Since the testing of software for noise mapping is usually done by comparing the estimated noise levels with experimental results, in order to verify and validate a developed software solution, there is a need to develop a plan for noise mapping software testing. Software verification should provide an answer to the question of whether the software meets the desired functionality and requirements, while validation should answer to the question of whether the software meets the real needs of users. To obtain the answers to these questions, it is necessary to execute unitary testing, i.e. independent testing of each program component, integration testing, which checks whether the connections between components are well defined and implemented, and the system (final) testing. Within the system testing, so-called reference tests are generated. Reference tests present the common conditions under which the system should perform once it is installed.

Therefore, for the purposes of software verification and validation, the test plan should be defined according to the project requirements, system model and project documentation. A separate specification should be made for each of the tests and should define purpose of the test, criteria for determining whether the requirements are met, as well as necessary data for testing.

In this paper the proposed tests for noise mapping software verification have been presented. For each of the proposed tests, necessary data for creating a noise map are given, as well as the reference mapping results, i.e. the sound levels calculated using the ISO 9613- 2 standard.

2. ISO 9613-2 STANDARD

ISO 9613-2 standard [9] specifies a method for calculating attenuation of sound during outdoors downwind propagation. The application of defined method enables prediction of the equivalent continuous A-weighted sound pressure level and also calculation of a long-term average A-weighted sound pressure level.

ISO 9613-2 standard defines octave-band algorithms for calculating the attenuation of the sound emitted by point sound source or an assembly of point sources. Line and area sources may be divided into line and area sections, respectively, and each section represented by a point source with certain sound power and directivity at the center of the section. Also, when only A-weighted sound power levels of the sound sources are known, the attenuation for 500 Hz may be used for estimation of the resulting attenuation.

The standard defines the algorithms for the following physical effects:

- geometrical divergence,
- atmospheric absorption,
- ground effect,
- reflection from surfaces,
- screening by obstacles.

The method for calculating attenuation of sound during propagation through foliage, industrial sites and housing is also specified by the ISO 9613-2 standard. Propagation over water surfaces is not covered by this standard. Also, the standard is not applicable to sound from aircraft in flight and to blast waves from mining, military and similar operations.

3. METHODOLOGY FOR SOFTWARE VERIFICATION

The developed method for the verification of noise mapping and prediction software consists of set of tests for comparing noise maps obtained by tested software and by using methodology defined by ISO 9613-2 standard. Proposed method tests modeling of the all physical effects covered by the standard. For the purpose of the software testing, functions for calculating the sound attenuation and A-weighted sound power levels according to ISO 9613-2 standard were developed by using MATLAB software package.

For each of the proposed tests the ambient temperature has value 30°C, while relative humidity of the air is equal 70%. These test parameters have been chosen in order to decrease high-frequency atmospheric absorption which, under test conditions, has value 59.3 dB/km for the octave band with 8000 Hz midband frequency (ISO 9613-2, Table 2). As the attenuation of the sound pressure level due to atmospheric absorption is approximately $(\Delta Leq)atm = d/100$ [dB] under defined conditions (temperature and air humidity), the distance between the sound source and the receiver d should be less than 100 m so that the atmospheric absorption influence becomes less than 1 dB. Also, in each test, noise sources are assumed to produce 100 dB sound pressure level with flat octave band spectrum.

Further in the paper are described proposed tests for noise mapping software verification and validation. Also, reference noise mapping results, i.e. the sound levels calculated according to ISO 9613- 2 standards, are given for each of the tests.

3.1. Horizontal propagation

In order to test modeling of the sound propagation in horizontal plane and calculating the sound attenuation due to geometrical divergence, omnidirectional point source is assumed to emit sound into free space with no physical obstacles to sound propagation. Equivalent continuous A-weighted sound pressure levels should be calculated for the network of receivers whose positions are defined by the coordinates [$5i$ $5j$ 0] m, where i=1,...,9 and j=1,...,9. In order to results be symmetric, sound source is located in the center of the network of receivers, so its position is given by the coordinates [25 25 0] m. Defined network provides sufficient receiver points for verifying the symmetry of the sound field. A-weighted sound pressure levels calculated in accordance with ISO 9613-2 standard are given in the Table 1.

Table 1 Horizontal propagation test

y[m] \ x[m]	5	10	15	20	25	30	35	40	45
5	57.4	58.5	59.5	60.3	60.6	60.3	59.5	58.5	57.4
10	58.5	60	61.5	62.7	63.1	62.7	61.5	60	58.5
15	59.5	61.5	63.7	65.8	66.8	65.8	63.7	61.5	59.5
20	60.3	62.7	65.8	69.8	72.9	69.8	65.8	62.7	60.3
25	60.6	63.1	66.8	72.9	98	72.9	66.8	63.1	60.6
30	60.3	62.7	65.8	69.8	72.9	69.8	65.8	62.7	60.3
35	59.5	61.5	63.7	65.8	66.8	65.8	63.7	61.5	59.5
40	58.5	60	61.5	62.7	63.1	62.7	61.5	60	58.5
45	57.4	58.5	59.5	60.3	60.6	60.3	59.5	58.5	57.4

3.2. Vertical propagation

This test is designed to check sound propagation modeling in vertical plane. The point source is assumed to emit sound equally in all directions in free space with no physical obstacles to sound propagation. Equivalent continuous A-weighted sound pressure levels should be calculated for five receivers distributed along vertical line, i.e. line parallel to z-axes of the coordinate system. The position of the first receiver point is defined by the coordinates [10 10 10] m, while the distance between neighboring points is equal 10 m. In order to study the symmetry, sound source is located at position of the middle receiver, so its position is given by the coordinates [10 10 30] m. Table 2 contains A-weighted sound pressure levels calculated in accordance with ISO 9613-2 standard.

Table 2 Vertical propagation test

z [m]	10	20	30	40	50
Leq [dBA]	60.6	66.8	98	66.8	60.6

3.3. Anisotropic source

In order to test calculation of the sound field of an anisotropic source, a sound source is assumed to emit energy into solid angle $\Delta\theta$=90°, $\Delta\varphi$=180°, i.e. into an angle of 90° around *y*-axes direction in free space. Equivalent continuous A-weighted sound pressure levels should be calculated for the network of receivers whose positions are defined by the coordinates [5*i* 5*j* 0] m, where *i*=1,...,9 and *j*=1,...,6. This network provides sufficient points for examining the distribution of the sound radiation. In order to enable symmetry of the sound field testing, sound source is located at position given by [25 10 0] m. In the region of sound radiation sound pressure level should be 6 dB higher than the sound pressure level due to omnidirectional source, while outside of this region sound pressure level has value 0 dB. The reference noise mapping results are given in the Table 3.

Table 3 Anisotropic source test

y[m] \ x[m]	5	10	15	20	25	30	35	40	45
5	0	0	0	0	0	0	0	0	0
10	0	0	0	0	104	0	0	0	0
15	0	0	0	75.9	78.9	75.9	0	0	0
20	0	0	69.7	71.8	72.8	71.8	69.7	0	0
25	0	66	67.5	68.7	69.2	68.7	67.5	66	0
30	63.4	64.5	65.6	66.3	66.6	66.3	65.6	64.5	63.4

3.4. Multiple sources

This test enables examining calculation of the sound field of multiple sound sources in horizontal plane in free space. Equivalent continuous A-weighted sound pressure levels should be calculated for the network of receivers whose positions are defined by the coordinates [5*i* 5*j* 0] m, where *i*=1,...,9 and *j*=1,...,9. In order to results be symmetric, positions of the sound sources are given by [5 5 0] m and [45 5 0] m. Each noise source is assumed to produce 100 dB sound pressure level with flat octave band spectrum. Table 4 contains noise mapping results obtained in accordance with ISO 9613-2 standard.

Table 4 Multiple sources test

y[m] \ x[m]	5	10	15	20	25	30	35	40	45
5	98	73	67.2	64.4	63.6	64.4	67.2	73	98
10	72.9	70	66.3	64	63.3	64	66.3	70	72.9
15	67	66.1	64.4	63.1	62.6	63.1	64.4	66.1	67
20	63.6	63.3	62.5	61.8	61.5	61.8	62.5	63.3	63.6
25	61.3	61.2	60.9	60.5	60.4	60.5	60.9	61.2	61.3
30	59.5	59.6	59.5	59.3	59.3	59.3	59.5	59.6	59.5
35	58.1	58.2	58.2	58.2	58.2	58.2	58.2	58.2	58.1
40	56.9	57	57.1	57.1	57.1	57.1	57.1	57	56.9
45	55.8	56	56.1	56.1	56.1	56.1	56.1	56	55.8

3.5. Ground effect

In order to check the prediction of the influence of the terrain hardness on sound propagation in the near and far field, calculation of the sound field in a horizontal plane above the hard, flat ground and, also, above the porous, flat ground, should be tested. Except the ground factor, both tests have the same testing parameters.

Equivalent continuous A-weighted sound pressure levels should be calculated for the network of receivers whose positions are defined by the coordinates [10*i* 10*j* 1] m, where *i*=1,...,9 and *j*=1,...,9. Position of the omnidirectional sound source is given by the coordinates [50 10 1] m. There are no physical obstacles to sound propagation in horizontal plane.

Choice of these parameters enables verification of calculation of sound pressure level in the near and far field, because it is achieved that the distance between the source and the receiver in some cases meets, while in other cases does not meet the condition $d<30\cdot(h_s+h_r)$, where h_s represents height of the source above ground and h_r is height of receiver above ground (h_s=h_r=1m). Also, defined network provides enough receiver points for testing the symmetry of the sound field.

Table 5 Hard ground test

y[m] \ x[m]	10	20	30	40	50	60	70	80	90
10	57.2	59.8	63.6	69.8	101	69.8	63.6	59.8	57.2
20	56.9	59.4	62.5	66.7	69.8	66.7	62.5	59.4	56.9
30	56.1	58.1	60.4	62.5	63.6	62.5	60.4	58.1	56.1
40	55.1	56.6	58.1	59.4	59.8	59.4	58.1	56.6	55.1
50	53.9	55.1	56.1	56.9	57.2	56.9	56.1	55.1	53.9
60	52.9	53.6	54.4	54.9	55.1	54.9	54.4	53.6	52.9
70	52	52.5	53	53.2	53.3	53.2	53	52.5	52
80	51.2	51.6	52	52.2	52.2	52.2	52	51.6	51.2
90	50.4	50.7	51	51.2	51.2	51.2	51	50.7	50.4

Table 6 Porous ground test

y[m] \ x[m]	10	20	30	40	50	60	70	80	90
10	53.1	55.9	59.8	66.3	98	66.3	59.8	55.9	53.1
20	52.8	55.4	58.8	63.1	66.3	63.1	58.8	55.4	52.8
30	52	54.1	56.5	58.8	59.8	58.8	56.5	54.1	52
40	50.9	52.5	54.1	55.4	55.9	55.4	54.1	52.5	50.9
50	49.6	50.9	52	52.8	53.1	52.8	52	50.9	49.6
60	48.4	49.3	50.1	50.7	50.9	50.7	50.1	49.3	48.4
70	47.1	47.9	48.5	48.9	49	48.9	48.5	47.9	47.1
80	46	46.6	47	47.3	47.4	47.3	47	46.6	46
90	44.9	45.4	45.7	46	46.1	46	45.7	45.4	44.9

Reference noise mapping results for flat, hard ground are given in the Table 5, while the sound pressure levels for flat, porous ground are given in the Table 6.

3.6. Sound barrier

This test is designed to check the calculation of the sound pressure levels when the screening obstacle (sound barrier) is positioned between the sound source and the receiver. Sound barrier is modeled as a thin, flat object with a rectangular vertical cross-section, whose vertices are given by [5 -150 0] m, [5 150 0] m, [5 -150 3] m, [5 150 3] m. Hence, the barrier is parallel to the *yz*-plane and its height is 3 m. Omnidirectional sound source is located at position [0 0 1.5] m, while the receivers are positioned on the other side of the sound barrier, and their positions are given by [5i 5j 1.5] m, where i=2, ...,6 and j=-2,...,2, so the symmetry of the sound field testing is possible. Since the distance between the receiver and the vertical edges of the barrier is more than four times larger than the distance between the barrier and the receiver, the influence of the diffraction around the vertical edges of the barrier may be neglected, so the prediction of the influence of diffraction over the top edge of the barrier on the sound pressure level may be tested. Also, horizontal dimension of the barrier normal to the source-receiver line is larger than the acoustic wavelength at the nominal midband frequency for each of the eight octave bands of interest, so that defined barrier may be considered as screening obstacle and taken into account when calculating the sound pressure level for each of the octave bands.

As, according to ISO 9613-2 standard, barrier attenuation for more than two barriers may be calculated approximately by choosing the two most effective obstacles and neglecting the effects of the others, verification of the calculation of the attenuation due to two parallel sound barriers is proposed, too. Testing parameters are the same as in the previous test, except that another sound barrier, given by [3 -150 0] m, [3 150 0] m, [3 -150 2.5] m, [3 150 2.5] m, is added between the sound source and the noise barrier defined in previous test.

Table 7 and Table 8 contain A-weighted sound pressure levels at receiver points when one or two barriers, respectively, are positioned between the sound source and the receiver points.

Table 7 One sound barrier test

y[m] \ x[m]	10	15	20	25	30
-10	49.1	47.4	45.6	44.1	42.8
-5	50.3	48.1	46.1	44.4	43
0	51	48.4	46.2	44.5	43
5	50.3	48.1	46.1	44.4	43
10	49.1	47.4	45.6	44.1	42.8

Table 8 Two sound barrier test

y[m] \ x[m]	10	15	20	25	30
-10	47.2	45.5	43.8	42.3	41
-5	48.5	46.3	44.3	42.6	41.2
0	49.1	46.5	44.4	42.7	41.2
5	48.5	46.3	44.3	42.6	41.2
10	47.2	45.5	43.8	42.3	41

3.7. Reflections

This test enables examining calculation of the sound field consisting of direct and reflected sounds. A-weighted sound pressure level should be calculated for the network of receivers whose positions given by the coordinates [5i 5j 1.5] m, where i=1,...,9 and j=1,...,9. The proposed location of the omnidirectional source is defined by the coordinates [25 25 1.5] m. Terrain is flat and hard, and the distance between source and receiver $d<30\cdot(h_s+h_r)$, so the attenuation due to ground effect is $Ag = -3$ dB. The reflecting obstacle is modeled as a flat object with a rectangular cross-section, whose vertices are given by [50 0 0] m, [50 50 0] m, [50 0 10] m, [50 50 10] m. Hence, the obstacle is parallel to the yz-plane, and its height is 10 m. Reflection coefficient has value 0.8 and, therefore, corresponds to walls of building with windows. A-weighted sound pressure levels calculated in accordance with ISO 9613-2 standard are given in the Table 9.

Table 9 Reflections test

y[m] \ x[m]	5	10	15	20	25	30	35	40	45
5	60.8	61.9	62.9	63.6	64	63.8	63.3	62.6	62.1
10	61.9	63.3	64.7	65.9	66.4	66	65	63.9	63.1
15	62.8	64.7	66.8	68.9	69.9	68.9	67	65.2	64
20	63.5	65.8	68.9	72.9	75.9	72.9	69	66.3	64.6
25	63.8	66.3	69.8	75.9	101	75.9	70	66.7	64.8
30	63.5	65.8	68.9	72.9	75.9	72.9	69	66.3	64.6
35	62.8	64.7	66.8	68.9	69.9	68.9	67	65.2	64
40	61.9	63.3	64.7	65.9	66.4	66	65	63.9	63.1
45	60.8	61.9	62.9	63.6	64	63.8	63.3	62.6	62.1

3.8. Foliage

This test is designed to check the calculation of attenuation due to sound propagation through foliage. The terrain is assumed to be flat and soft. The position of the sound source is given by [0 20 1.5] m. The source is assumed to emit sound equally in all directions. A-weighted sound pressure levels should be calculated for the network of receivers whose positions are given by [5i 5j 1.5] m, where i=1,...,7 and j=1,...,7. Height of the trees is 3 m and the area with vegetation may be represented by a rectangle in xy-plane whose vertices are given by [4.5 0 0] m, [30.5 0 0] m, [30.5 40 0] m, [4.5 40 0] m. Thus, the source is outside the area with vegetation, while some of the receivers are within this area, but to each receiver sound propagates through foliage of trees. In some cases the total path length through the foliage d_f is less than 10 m, so there is no additional attenuation due to foliage A_{fol}, while in other cases d_f is between 10 m and 20 m and A_{fol} = [0 0 1 1 1 1 2 3] dB, or between 20 m and 200 m, when A_{fol} attenuation depends on the length of propagation distance through the foliage d_f, and has value d_f·[0.02 0.03 0.04 0.05 0.06 0.08 0.09 0.12] dB (d_f is in meters). Table 10 contains desired noise mapping results obtained in accordance with ISO 9613-2 standard.

Table 10 Foliage test

y[m] \ x[m]	5	10	15	20	25	30	35
5	62.3	61.1	58.1	56.5	54.6	52.9	51.7
10	65.5	63.3	59.6	57.6	55.5	53.6	52.3
15	69.6	65.5	60.8	58.4	56.2	54.1	52.6
20	72.7	66.5	61.3	58.6	56.4	54.2	52.7
25	69.6	65.5	60.8	58.4	56.2	54.1	52.6
30	65.5	63.3	59.6	57.6	55.5	53.6	52.3
35	62.3	61.1	58.1	56.5	54.6	52.9	51.7

3.9. Housing

This test is designed to check the calculation of attenuation due to sound propagation through the built-up region of houses. The terrain is assumed to be flat and hard. The region with houses may be represented by a rectangle in xy-plane whose vertices are given by [4.5 0 0] m, [24.5 0 0] m, [24.5 40 0] m, [4.5 40 0] m. Buildings height is 6 m, and the density of the buildings is 0.7. The location of the omnidirectional sound source is given by the coordinates [0 25 1.5] m.

Table 11 Housing test

y[m] \ x[m]	25	30	35	40	45
15	59.3	57.9	56.6	55.4	54.4
20	59.9	58.3	56.9	55.7	54.6
25	60.1	58.4	57	55.8	54.7
30	59.9	58.3	56.9	55.7	54.6
35	59.3	57.9	56.6	55.4	54.4

A-weighted sound pressure levels should be calculated for the network of receivers whose positions are given by [5*i* 5*j* 1.5] m, where *i*=5,...,9 and *j*=3,…,7. Desired noise mapping results for the housing test are given in the Table 11.

4. Conclusion

This paper presented the methodology developed for testing the software for noise prediction according to the ISO 9613-2 standard. Designed tests enable examining calculation of the sound attenuation due to geometrical divergence, atmospheric absorption, ground effect and sound barriers. Calculations of the sound field of an anisotropic source or multiple sound sources are covered by specific tests. Proposed methodology allows testing the prediction of the sound field consisting of direct and reflected sounds. As ISO 9613-2 standard defines algorithms for calculation of attenuation due to sound propagation through foliage or built-up region of houses, specific tests are proposed for examining modeling of these physical effects. Proposed testing methodology should be improved and expanded by adding tests for the propagation above uneven terrain and diffraction around vertical edges of barrier.

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METODOLOGIJA VERIFIKACIJE SOFTVERA ZA PRORAČUN SLABLJENJA ZVUKA U SKLADU SA ISO 9613-2 STANDARDOM

Jedan od ciljeva projekta "Razvoj metodologija i sredstava za zaštitu od buke u urbanim sredinama" jeste razvoj softverskog alata za izradu lokalnih mapa buke. U cilju verifikacije softverskog rešenja, predložena je metodologija testiranja softvera za predikciju nivoa buke u skladu sa ISO 9613-2 standardom. Primena validacione metodologije omogućava testiranje modelovanja svih fizičkih efekata obuhvaćenih pomenutim standardom. U okviru rada su opisani predloženi testovi za verifikaciju softvera za mapiranje buke sa referentnim rezultatima mapiranja, odnosno nivoima zvuka proračunatim primenom ISO 9613-2 standarda.

Ključne reči: *mape buke, verifikacija softvera, ISO 9613*