The method of mapping of acoustic field, emitted by sources of sound in the environment, with implementation of the MEMS IMU unit and laser devices

Abstract

During the course of the research, a methodology of measurement of sources of noise was developed, along with measurement models and measurement sets. The latter were equipped with microphones, acoustic pressure level meters, devices determining spatial orientation of the measurement (laser rangefinder, inertial measurement unit 3D IMU) and software processing the data, obtained including final spatial mapping of the acoustic field. The system has been successfully tried in large indoor areas.

Keywords: acoustic field, inertial unit, laser device.

1. The acoustic mapping method

The research was aimed at examination of the aptitude of new methods and measuring instruments in spatio-temporal measurements of the acoustic field generated by the source of sound in the environment. Former research was dedicated to application scanning laser vibrometer to mapping the vibrating sound in the environment. Former research was dedicated to measurement sets. The latter were equipped with microphones, acoustic pressure level meters, devices determining spatial orientation of the measurement (laser rangefinder, inertial measurement unit 3D IMU) and software processing the data, obtained including final spatial mapping of the acoustic field. The system has been successfully tried in large indoor areas.

The applicability of the invented method for spatial mapping of the acoustic field was tested indoors. The results obtained could be easily transferred into examination of the outdoor areas.

The following actions aimed at effective mapping of the acoustic field emitted by sources of the sound were undertaken:
- development of the method of measurement and construction of the measuring set;
- selection of model sources of noise, conducting preliminary model research – laboratory;
- undertaking the preliminary environmental research, together with compilation of the measured data and determination of its aptitude to apply in spatial maps of the acoustic field.

The concept of a mobile system enabling an effective obtainment of complex data on a level of noise and directions of its propagation in the field, assumed a necessity of automatic, permanent registration of those parameters, together with parameters of orientation and location of the measuring system itself. Rationalization of actions, aimed at effective formation of the acoustic climate on the territories subjected to the acoustic protection, resulted in construction of a prototype of such system is two versions (with two different sound level meters and two different systems of data acquisition). Both versions were equipped with inertness sensors integrating accelerometers, gyroscopes and magnetometers, as well as a laser rangefinder for the spatial orientation of the foreseen mobile measuring system.

The laboratory research enabled selection of the optimum measuring set and determination of parameters of a set according to a point and model source of sound, located in an indoor area of a size 6m×5m×3m. Searches enabled to verify the directional (angular) relations and the influence of the geometry of the facility (overlapping of reflected waves). Preliminary research was carried in the spacious conference hall (assembly hall of the Institute). This way, the applicability of the adapted method to analysis of the acoustic field in facilities such as assembly halls or concert halls has been determined. The obtained data could be easily transposed to an outdoor research.

2. Structure and components of the acoustic measuring probe

The measuring set of an acoustic probe consisted of a laser rangefinder Disto D8, co-operating through the Bluetooth connection to the computer recorder, inertial sensor Microstain, connected through the USB 2.0 connector to the same computer recorder, and a acoustic pressure level meter equipped with a microphone with an analog output, connected by a coaxial cable to a digital oscilloscope with memory (Fig. 1). The inertial sensor 3D is located in the rear of the device, between the laser rangefinder and a acoustic pressure level meter. Axes X, Y, Z – its the height.

All elements of the acoustic probe has been installed on a common platform. The laser rangefinder Leica Disto D8, that is visible in the Fig. 1, on the left side of the measuring head, was used to determine the distance between a measurement point and the source, or a point tracked at the direction of detection of a level of acoustic pressure in the facility, for the reflected waves.
The laser rangefinder Leica Disto D8 is equipped with a laser sight, color display with a diagonal of 2.4 inches, inclination sensor 360° and the Bluetooth connector. Thanks to the free software DISTO Transfer measurements’ results can be wirelessly sent to the outer computer and there automatically inserted to any application (AutoCAD, Word, Excel).

Fig. 1. Prototype measuring set of an acoustic probe – an overall view

It assures the range of a measurement up to 200 m and a ±1 mm accuracy. The dust-proof case fulfills all requirements of the IP54 norm. It has a following dimensions: 143.5x55x30 mm, and the weight with batteries equals to 205 g. The inertial sensor 3DM-GX4-25, produced by the company MicroStrain, which is depicted in the Fig.2., was used for automated constant measurement of the spatial orientation of the acoustic probe.

Fig. 2. The inertial sensor MicroStrain 3DM-GX4-25

3DM-GX4-25™ is a miniature AHRS (Attitude Heading and Reference System) based on the technology of MEMS sensors. It combines triaxial accelerometer, triaxial gyroscope, triaxial magnetometer, sensors of temperature, pressure altimeter and a processor with a Kalman filter, which allows a static as well dynamic assessment of those relations and measurements of inertia.

Through the USB 2.0 connector, the sensor cooperates in real time with the delivered software, what enables a constant registration of measured parameters.

The input data encompassing accelerations, angular velocity, magnetic field, assessment of orientation (Euler angles, orientation matrix, quaternions) and uncertainty of location.

The typical accuracy of measurement of an angle equals to ±0.25 deg RMS (roll & pitch) and ±0.8 deg RMS (yaw).

The range of angles’ measurement is 360°, around all 3 axes.

The research of the emitted noise was carried using:

- the sound level meter, a part of a SVAN 948 type no. 12601 acoustic analyzer with SV12L type no. 10105 preamplifier produced by SVANTEK and with the SV22 type no. 41012553 microphone produced by SVANTEK, class accuracy 1;
- the sound level meter, a part of a SVAN 945A type no. 6410 acoustic analyzer with SV11 type no. 5834 preamplifier produced by SVANTEK with the 40AN type no. 42862 microphone produced by G.R.A.S.; class accuracy 1;
- the 2236 no. 1879901 type sound level meter, cooperating with the 4188 type no. 1868575 microphone, class accuracy 1; produced by Bruel and Kjaer;
- the KA-50 no. 026/04 type acoustic calibrator, produced by Sonopan Bialystok.

The measuring set was calibrated before as well as after the research, according to instructions provided the manufacturers of those devices.

3. Measurements’ results

Tests of the devices were preliminary carried under laboratory conditions in a facility of the Laboratory of the Laser Technique of the Central Mining Institute. Afterwards – after discussion of the obtained results and modification of the acoustic probe and entire measuring set, the tests were carried in a large capacity indoor facility – in the assembly hall of the Institute.

For the purposes of laboratory tests, the fixed locations of sounds of source and the measurement system were adapted. Distances, directional angles and angles of inclination of the measuring head had been varying. The level of the acoustic pressure from the direction of the source and other chosen directions were measured, with a parallel registration of angular spatial orientation of the measuring head and distance to the source, as well as borders (walls) of the facility along subsequent radius vectors (laser beams generated by the rangefinder). Those radiuses are coaxial, parallel to the longitude axis of the microphone. Results of a measurement of an orientation of the device and spatial distribution of points tracked by laser were determined with an inertial sensor, laser rangefinder, spreadsheets, self-produced software in Delphi 5.0 and a program Rhinoceros 4.0.

Fig. 3. Collation of distance records recorded by the laser rangefinder Disto D8 with angles (Pitch, Yaw, Roll) from the Microstrain inertia sensor obtained during laboratory tests of the device. The vertical axis depicts distance (in meters) for the upper diagram, and – for angular characteristics for the other three diagrams - values of angles in radians. Horizontal axes represent the timelines and are described with numbers of the subsequent probes of measured quantities.
Fig. 3 presents collation of distance records obtained by the laser rangefinder Disto D8 with angles (Pitch, Yaw, Roll) from the Microstrain inertia sensor. The vertical axis depicts distance (in meters) for the upper diagram, and – for angular characteristics for the other three diagrams – values of angles in radians. Horizontal axes represent the timeline and are described with numbers of the subsequent probes of measured quantities. The basic difficulty was connected to alignment those numerations to the data obtained through the laser rangefinder and the inertia sensor.

The table in the Figure 4 presents the spatial configuration of laser-tracked points, determined basing on data from the inertia sensor and the laser rangefinder.

Table 1. Collation of measurement values obtained in the subsequent measurement points: Distance (Disto), Yaw angle (Microstrain) (towards to the main measurement axis S-0 from Fig.5) and the level of the acoustic pressure (the 2236 type noise level meter with the 4188 type microphone, produced by Bruel and Kjaer)

<table>
<thead>
<tr>
<th>No.</th>
<th>Disto (mm)</th>
<th>Yaw (deg)</th>
<th>Acoustic pressure (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6367</td>
<td>3.4</td>
<td>65.9</td>
</tr>
<tr>
<td>1</td>
<td>6551</td>
<td>35.2</td>
<td>66.2</td>
</tr>
<tr>
<td>2</td>
<td>5581</td>
<td>-44.4</td>
<td>59.6</td>
</tr>
<tr>
<td>3</td>
<td>3137</td>
<td>0.0</td>
<td>74.8</td>
</tr>
<tr>
<td>4</td>
<td>9497</td>
<td>0.8</td>
<td>64.6</td>
</tr>
</tbody>
</table>

In the subsequent measurement points, measurements of a level of acoustic pressure were performed as well. Fig.7. presents those values of a level of acoustic pressure (the 2236 type noise level meter with the 4188 type microphone; produced by Bruel and Kjaer), marked on locations of measurement points obtained only basing on data registered by a rangefinder Disto and a sensor Microstrain. Table 1 contains collation of measurement values from the subsequent points: distance (Disto), Yaw angle (Microstrain) (towards to the main measurement axis S-0 from Fig.5) and the level of the acoustic pressure (the 2236 type noise level meter with the 4188 type microphone; produced by Bruel and Kjaer).

The wideband speaker, stimulated with a frequency of 1 kHz from the stabilized generator, was used as a source of sound.

Fig. 6. presents qualitatively the way of assigning the registered distances to the ceiling measured by the laser rangefinder Disto before each measurement to angles Roll (corresponding with angular inclinations of the measuring head from the horizontal plane), registered by a Microstrain sensor. The vertical axis of the upper diagram presents distances in meters, while the vertical axis of the second diagram represents angular values in radians. Horizontal axes represent the timeline and are described with numbers of the subsequent probes of measured quantities. The markers that are visible on the lower diagram (large vertical inclinations) enabled performing such alignment. This, in turn, allowed to determine the Yaw angles (corresponding with rotations around the vertical axis) and verification of indications of the inertia sensor with the factual configuration of the measuring scheme from the Fig. 5.
5. References


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4. Summary and conclusions

The presented solutions consisting of the new measuring method and a related prototype of measuring head, in the future could allow to undertake actions appropriate to shaping the acoustic climate on the terrains subjected to acoustic protection. It would be achieved by implementation of the methods, devices and programs enhanced with the above described measuring systems and procedures.

It would be favorable to replace the microelectronic inertial sensor IMU 3D (being a miniaturized complex of inertial and MEMS type magnetic sensors) forming a part of the probe with an integrated GPS system, what would assure also the absolute spatial positioning of every measurement point towards the global co-ordinate system. Also acoustic pressure level meters should be replaced with directional microphones (in order to minimize the size and mass of the head of the measuring head) or sound-level sensors (inter alia in order to obtain the complete information on directions of sound propagation in the mapped area of the acoustic field generated by sources of sound in the environment). As the research has been successfully carried for large, even very large capacity indoor areas, the proposed method could allow in the future to facilitate determination of acoustic attributes for facilities such as lecture or concert halls. It was not required to carry the research in special acoustic-research specific facilities (reverberation or sound-absorbing chambers). In the next stage of the research, the obtained results could be transferred also to analogue research carried in the outdoor environment, using devices enhanced with an integrated GPS system and the pressure sensor.

5. References