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Automated Sound Intensity Measuremant With Robot And Intensity Probe

Nikola Knežević [1], Miloš Bjelić [2] and Kosta Jovanović [1]

[1]ETF Robotics Laboratory, Signals & Systems Department, School of Electrical Engineering, University of Belgrade, Serbia
[2]Acoustics Laboratory, Department of Telecommunications, School of Electrical Engineering, University of Belgrade, Serbia

knezevic@etf.rs, bjelic@etf.rs, kostaj@etf.rs

Abstract— **This paper presents the procedure for measuring the sound intensity. The procedure was realized in such a way that the robotic arm carries the intensity probe and performs automatic positioning at the appropriate measurement points. In order to determine the deviation value, a comparison was performed of sound intensity measurement obtained using robot and the measurement manually performed by two people. Also, the measurement process was repeated for both the automated and manual positioning of the probe, which resulted in deviation values for these two types of measurements. The differences in the total sound power of the source obtained by automated and manual measurements of the sound intensity were also analyzed. Using a robot arm significantly facilitates the measurement process and achieves higher measurement accuracy. Such use of robots can be of interest in measuring the intensity of sound of complex sound sources in a large number of points, where high accuracy of intensity measurement is required.**

Keywords- automation; intensity of sound; intensity probe; measurement; robot; sound power;

I. INTRODUCTION

The most commonly used procedure for measuring the intensity of sound is the measurement using the intensity probe. This measurement method involves the use of two microphones at a close distance [1]. Microphones form an axis which is the direction in which the probe determines the value of the sound intensity. The intensity probe is used in various engineering areas: construction acoustics [2], the determination of the noise of machines which have complex geometric shapes [3-4], the detection of machine defects [5], etc. The advantage of using intensity in relation to the sound pressure measurement for calculating the sound power of the source is that the intensity is determined only for the direction that the two microphones of the intensity probe form. In this way, a spatial selection of the sound sources which are being analyzed is performed, and the influence of other sources that could potentially lead to errors in the analysis result is eliminated. The measurement can be performed in several points or continuously, so that a certain curve in the space is formed by the probe [6]. The measurement in discrete points is more commonly used in practice because it allows for a more comfortable measurement process because a break can be taken between individual points. If the measurement is performed in discrete set of points, a network of measurement points is formed a few centimeters away from the sound source. The intensity of the sound in space is usually displayed on a two-dimensional graph with color coded intensity values.

The measurement of intensity using an intensity probe requires ideally phase-paired microphones. Even with well paired microphones and additional phase compensation, a measurement error will occur, since achieving ideal pairing is impossible in practice. Additional measurement errors can occur due to the measuring equipment. Theoretical range of values of these errors is addressed in the literature [1]. Errors in intensity measurements also occur due to the non-stationary sound field emitted by sound sources [7], as well as due to the large difference in the oscillation speed and the sound pressure on the measuring microphones [7]. However, largest errors in intensity measurements occur in the process of positioning the probe at a point in space and retaining the same position during the recording of the signal [7].

It is common for the analysis of complex sound sources that the sound intensity measurement is performed in a large number of points. Also, measuring the intensity at each point takes a few seconds or tens of seconds, and with a large number of measurement points, this process becomes extremely demanding for the person performing the measurement. The intensity probe must be kept at the same distance from the measurement surface for all the measurement points. The axis formed by the two microphones must be perpendicular to the measurement plane during the measurement [6]. Therefore, the position of the probe in space needs to be precise. Since in this procedure a person positions the probe by hand, the fulfillment of these requirements is not

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This paper is a revised and expanded version of the paper presented at the XVII International Symposium INFOTEH-JAHORINA 2018 [17].

Corespondence to: M. Bjelić (bjelic@etf.rs) an easy task. During the measurement process, a person experiences fatigue, and therefore exact positions of the probe cannot be kept for all measurement points. Additionally, because of fatigue, a person moves the probe, or its axis, in relation to the measurement plane during the measurement. For the reasons listed above, it is inevitable that an error is introduced in the intensity measurement process.

Errors due to the inaccuracy of probe positioning in space can be detected and analyzed by measuring the intensity of the same source several times. However, in this way, it is only possible to determine the deviations between the individual measurements, but not the exact value of the intensity of sound generated by a complex source. The exact intensity value in individual points could be determined using an automated probe positioning system. The intensity value from which the error of imprecise positioning is eliminated is considered to be the exact value. However, remaining errors of different nature mentioned above will still be present. For the probe positioning procedure various types of robots can be used. The robots used in this procedure must have three degrees of freedom to provide the required positioning. The robots which are used today in the industry provide a positioning accuracy of 10^{-4} m [8], which is more than sufficient accuracy for this application. Measurement using robots, in addition to a more precise positioning of the probe in space, is also incomparably easier than the "hand-held" measurement. Using a robot, it is easy to repeat the measurement procedure, which allows you to see the effects from other listed causes of errors in the measurement.

In this paper, an analysis was performed of the possibility of using robots for automating the method of measuring the intensity of sound. The motivation for this research is the reduction of the measurement error due to probe positioning. Also, the goal is to facilitate measuring and reduce the time needed to measure complex sources. The deviations that occur in intensity measurements using robots and hand-held measurements are analyzed, and the dimensions of these deviations are determined. Non-robot measurements were performed by two people in order to analyze if there is a dependency of the measurement error when different persons perform the measurement procedure. Repeated robot measurements were performed to see the deviation value in measurements when the probe positioning was performed precisely. In this way, it is possible to determine the error values that occur due to other factors that do not depend on the positioning of the probe. Intensity measurement can be used to calculate the total sound power of acoustic sources. The paper also analyzes differences in the total sound power, calculated on the basis of intensity measurement using automated measurement and manual measurement.

The work is organized as follows. The second chapter presents the method for measuring the intensity of sound using two microphones. Chapter 3 shows the equipment used in the experiments as well as the experimental setting. The following chapter presents the experimental results of the measurement and the discussion of the results obtained. Finally, a conclusion is made about the possibility of applying the presented methodology which uses the intensity probe and the robot.

II. MEASURING THE INTENSITY OF SOUND USING THE INTENSITY PROBE

This chapter shows the procedure for determining values of sound intensity using the intensity probe, and the advantages and limitations of this measurement method.

A. *Measuring the sound intensity*

The sound intensity is a vector and can be calculated by knowing the speed and sound pressure, that is:

$$\vec{I} = p\left(\vec{r},t\right)v\left(\vec{r},t\right) \tag{1}$$

Speed measurement is a difficult task in practice. Speed is usually determined indirectly by measuring some other physical quantities, which are easier to measure. The sound pressure can be determined simply by using a microphone. Knowing the dependence of the pressure and the oscillation speed, the intensity of the sound can be determined. The pressure and speed relationship is given by the following equation:

$$\rho_0 \frac{\partial v}{\partial t} = -\mathrm{grad}p, \tag{2}$$

where ρ_0 is the density of the air. Based on this equation, the sound velocity can be calculated as:

$$v = -\frac{1}{\rho_0}\int \mathrm{grad}p\, dt \tag{3}$$

However, calculating the pressure gradient requires the gradient to be determined over all three axes of the Cartesian coordinate system. Calculating the speed in this way would require at least three measurements. If it is assumed that sound propagates only in some direction u, gradient of the sound pressure can be calculated as:

$$\mathrm{grad}p = \frac{\partial p}{\partial u}, \tag{4}$$

Based on equation (1) and equation (4), the sound intensity is calculated as follows:

$$\vec{I} = -\frac{1}{\rho_0} p\left(\vec{r},t\right)\int_0^t \frac{\partial p\left(\vec{r},t\right)}{\partial u}\, d\tau \tag{5}$$

In practice, averaged sound intensity value is usually used, at some time interval t, which is defined by equation (5) as:

$$\langle\vec{I}\rangle = -\frac{1}{\rho_0}\langle p\left(\vec{r},t\right)\int_0^t \frac{\partial p\left(\vec{r},t\right)}{\partial u}\, d\tau\rangle \tag{6}$$

In Fig. 1 a system is shown with two microphones in the axis and at a close distance, which is determined by the spacer placed between them. Such a measurement system is known in the literature as the intensity probe [4]. Two microphones form a direction u in which it is possible to determine the gradient of the sound pressure, and therefore possible to calculate the oscillation speed. In Fig. 1, is also shown a simplified sound field of the sinus shape. The gradient of sound pressure is displayed in full line. By introducing a certain approximation, the gradient of pressure could be determined only on the basis of the measured pressure values using two microphones. The approximation is defined by the equation (7) and represents the reduction of the gradient to the difference in the pressure at a finite distance.

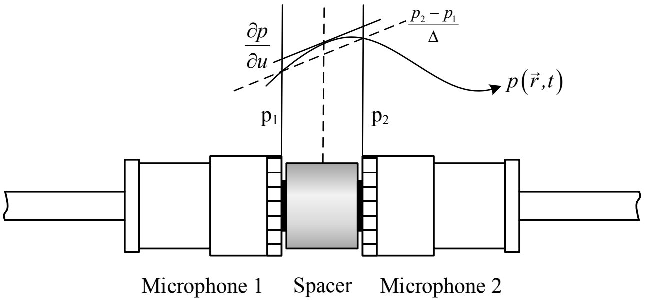


Fig. 1 Sound pressure gradent approximation using two microphones at a close distance.

$$\frac{\partial p}{\partial u} = \frac{p_2(\vec{r},t) - p_1(\vec{r},t)}{|r_2 - r_1|} = \frac{p_2 - p_1}{\Delta} \tag{7}$$

$$\langle p \rangle = \frac{p_1 + p_2}{2}, \tag{8}$$

Finally, the sound intensity value for a given time interval t is obtained by replacing the equations (7) and (8) within the equation (6).

$$\langle \vec{I} \rangle = I = -\frac{p_1 + p_2}{2\Delta\rho_0}\int_0^t (p_2 - p_1)\, d\tau \tag{9}$$

B. *Measurement limits with intensity probe*

The approximation introduced in equation (7) is valid in cases where the wavelength of sound whose intensity is determined is greater than the distance between the microphones. In cases where this distance is not negligible, approximation is not justified. In other words, the obtained sound intensity value is incorrect. In Fig. 2, a microphone pair from Fig. 1 is displayed, but in this case the frequency of the analyzed sound is several times higher. From the picture it can be noticed that the gradient value of sound pressure deviates significantly from the difference in the sound pressure obtained by two microphones.

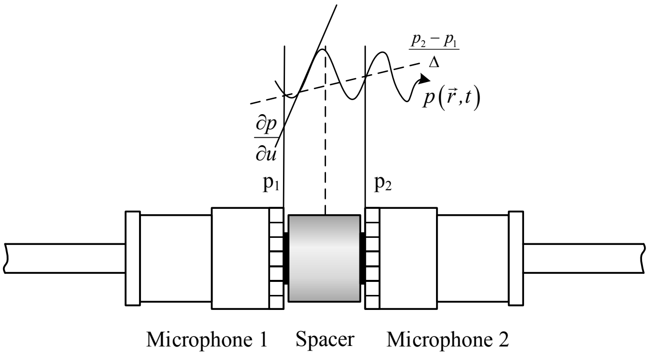


Fig. 2 High frequency limitation to sound pressure gradient approximation

Therefore, the adopted dimension of the distancer between the microphones defines the operating frequency range in which it is possible to use the intensity probe to determine the exact values of the intensity of the sound. Another limitation on high frequencies is the occurrence of diffraction and scattering on the distancer and the microphones contacts. In the literature and practical applications, three values of distancers have been used: 8 mm, 12 mm and 50 mm.

C. *Total sound power of the source*

In the literature, the measurement of the sound intensity is often used to obtain the total sound power of the sound source. The acoustic power of the sound source can be determined from the following equation [9]:

$$P = I \cdot S\,[\mathrm{W}], \tag{10}$$

where I represent the sound intensity, and P the surface at which the intensity is measured. In the literature, it is usual to use the sound power level, which is determined as [9]:

$$L_w = 10\log_{10}\frac{P}{P_0}\,[\mathrm{dB}], \tag{11}$$

where P_0 is the reference value for calculating the sound power and is 2 pW.

Measurement of intensity is performed in discrete points distributed over the surface S. In order to obtain the total sound power of the source, it is necessary to summarize the contributions of intensity I_k,, measured at all measurement points. The number of measurement points can be arbitrary, and the total sum obtained must be scaled with the number of measurement points. The total power of the sound source is calculated using the sound intensity measured in the N measurement points as follows:

$$P_{TOTAL} = 10\log_{10}\left(\frac{1}{N}\frac{\sum_{k=1}^{N} I_k \cdot S}{P_0}\right), \tag{12}$$

III. DESCRIPTION AND SETUP OF EXPERIMENT

A. *Used equipment*

For measuring the sound intensity an intensity probe Brüel & Kjær 3599 with phase-paired microphones was used [10]. Microphones are placed at a mutual distance of 12 mm, which is provided by a distancer between them. For the size of the used distancer, the sound intensity measurement will be in the range from 250 Hz to 5000 Hz. For the acquisition of the signal the acquisition system Brüel & Kjær LAN-XI was used [11]. When measuring "from the hand" with the probe, a thin cardboard stopper, 8 cm long is placed on the probe, in order to maintain the same distance from the sound source. In this way, the positioning of the probe is ensured, which is not practice, and this method of manual measurement is the best possible case.

A Distributed Mode Loudspeaker (DML) speaker was used as a sound source in the experiments [12]. The operation of this speaker is based on emitting the sound on a flat hard board by a mechanical exciter ("shaker") [13]. This sound source is chosen because it has a flat surface, and the measurement plane can be set so that the measurement points have the same distance from the sound source. In addition, it is possible to draw the position of the measurement points on surface of the DML speaker, which makes it easier to measure the intensity in the case of manual measurement. The signal used was a maximum length sequence (MLS) sequence [14] of long duration.

In this setup, the robot ABB IRB 120 [15] was used, which belongs to the category of small industrial robots. This robot has 6 degrees of freedom and has an arm reach of 0.58 m. Due to its characteristics it is ideal for smaller production lines as well as for laboratory applications. This robot has the ability to program and test the program offline in the software package Robot Studio [16]. This software package enables integration of the 3D model of the object, which enables the creation of a program in a fast and efficient way.

The program code that robot uses is designed to allow the user to easily control program flow, as well as the ability to select the position at which the sound intensity is measured. The user selects the number of points and the area of the measurement plane, and then automatically allocates the equidistant points over the given surface. Fig. 3 shows the layout of the measurement points and the robot position in software package Robot Studio. At first the robot is positioned at the edge of the measurement area in front of the sound source, after which the recording starts. The teach pendant screen is interactive and the information is printed on it. Also, the controls on the screen can be accessed from the arbitrary recording position. This option is useful if the user finds it necessary to perform recording at some position again or if a recording error occurred.

B. Experiment setup

Measurement was performed at the Laboratory of Robotics at the Faculty of Electrical Engineering in Belgrade. Sound intensity measurements were performed at 100 measurement points, arranged so as to make a square, as in Fig. 4. The distance between neighboring points is 5 cm, thus achieving good spatial resolution and covering the entire surface of the DML speaker. The distance of the plane at which the measurement is performed from the speaker plane is 8 cm.

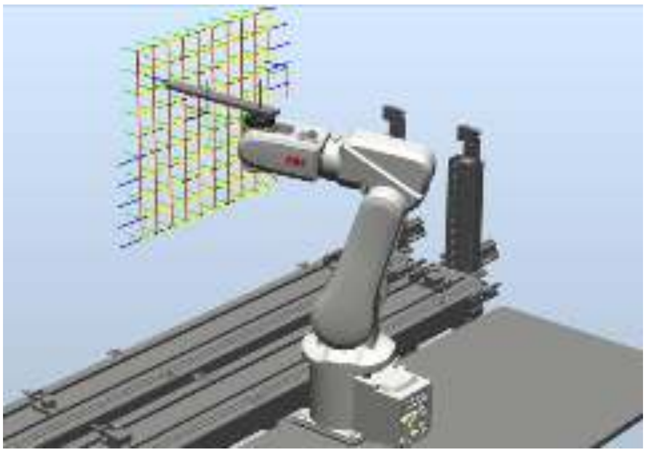


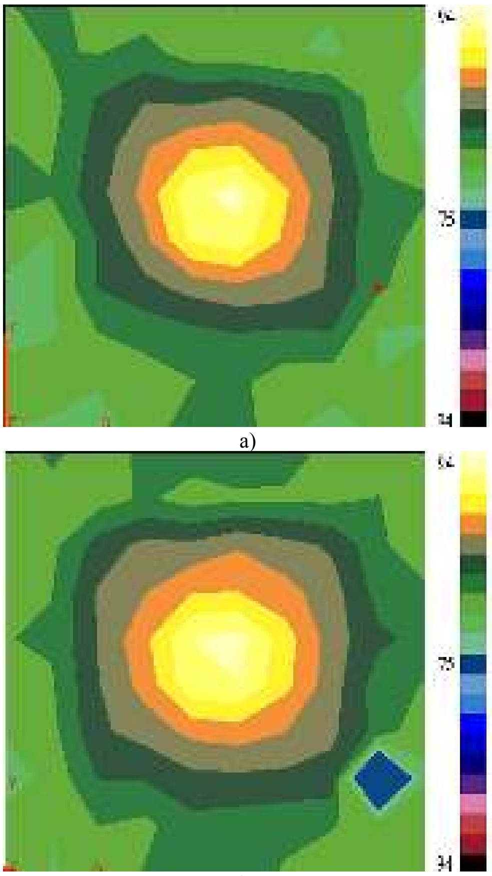
Fig. 3 Robot and measurement point distribution in Robot Studio software.

Fig. 4 Experimental setup: Robot carrying the intensity probe and the DML speaker.

The speaker is mounted on two stacks in front of the robot on whose arm the intensity probe is attached. The intensity probe is located far from the walls and obstacles in the room that are perpendicular to the axis of the probe, thus avoiding the sound reflection. The probe carrier is fixed far away from the robot, so the effect of reflected energy from the robot at the measurement point is reduced. The experiment setup is shown in Fig. 4.

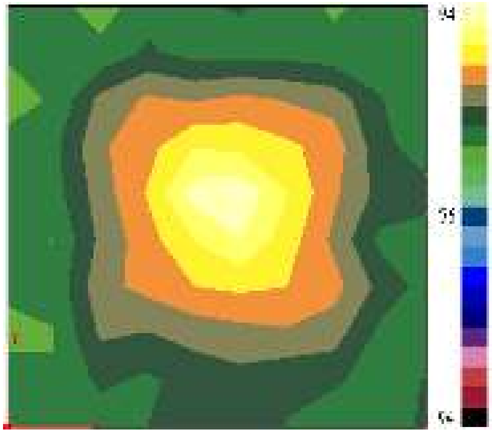
IV. RESULTS OF EXPERIMENTS AND DISCUSSIONS

Fig. 5 shows the results of measuring the sound intensity of the DML speakers obtained by automated robot measurement (Figure 5a)), and manual measurements performed by two people (Figures 5b) and c)). The sound intensity is expressed in dB, and the dynamic range on the picture is 15 dB.



a)

b)



c)

Fig. 5 Sound intensity levels obtained using a) robot, b) handheld measurement 1 (Person 1), c) handheld measurement 2 (Person 2).

The results presented were obtained for the 4-octave frequency range. Observed octaves are: 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. This frequency range is chosen because it is in the operating range of the intensity probe with the selected distancer and because this is the operating frequency range of the DML speakers.

Based on the presented results, certain differences are observable between the individual measurements. In both measurement methods, the maximum intensity value occurs at the point where the mechanical exciter is attached to the plate. However, the values that occur around the maximum are not the same for the three observed cases. Also, in places where the speaker plate was leaning on the carriers, differences in measured intensity appear. The biggest differences occur in cases where the measurement using the probe was performed by Person 2. Based on Fig. 5, it can be concluded that the differences between these two methods of measurement exist, but they cannot be quantified. Therefore, for the quantification of differences between individual measurements, the distribution of the intensity difference is introduced. Based on the results of two intensity measurements, the intensity difference for the individual measurement points was calculated and in this way a series of 100 data points was obtained. From the data obtained in this way a histogram with 10 classes of the same width was calculated. Also, for further interpretation of the results, the mean values and the standard deviation of the difference between the intensity values for the two measurements are calculated.

In Fig. 6, a normalized histogram of the difference is shown, between the two repeated intensity measurements using a robot. Normalization is performed with the total number of measurement points. Using the robot in the measurement, the exact positioning of the probe was performed in each repeated measurement, but there are still deviations between the two repeated measurements. The maximum deviation value in this experiment is up to 1 dB. Differences in individual points are due to other effects mentioned in the introduction. There are deviations of more than 1 dB, however the likelihood of their occurrence is small. In other words, there is a small number of points in which the difference in the repeated measurement with the robot occurred.

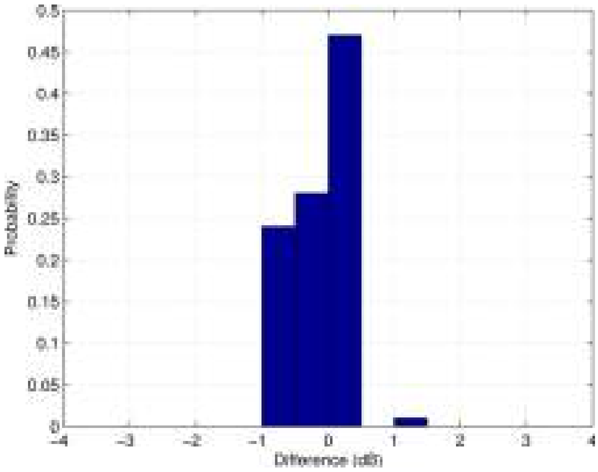


Fig. 6 Normalized histogram of the differences between the two repeated measurements using the robot.

TABLE I. STANDARD DEVIATION AND MEAN VALUE OF THE DIFFERENCE BETWEEN MEASUREMENTS

Experiment	Mean Value (dB)	Standard deviation (dB)
Robot – Robot	0.149	0.393
Robot – Person 1	0.549	0.631
Robot – Person 2	0.411	0.697
Person 1 – Person 1	-0.013	0.487
Person 2 – Person 2	-0.019	0.855
Person 1 – Person 2	-0.139	0.545

Table 1 shows the mean values and standard deviations for the performed experiments. From the table it can be seen that standard deviation, i.e. the deviation from the mean error value, is least for the experiment with repeating intensity measurements using robots in relation to all other analyzed situations. In Fig. 7 and Fig. 8, normalized histograms are shown of the difference between the repeated robotic measurements and hand-held measurements of Person 1 and Person 2. In these experiments there are deviations of over 2 dB in relation to the situation of the repeated measurements using robots. The deviation value in this case is two times larger than in the previous experiment. There are some differences between the two graphics shown, but the deviation margins are roughly the same. Based on the data in Table 1, it is noted that deviations also reflect on the increase in the standard deviation when measuring is done manually, in relation to the case when the robot is used for the measurement. Based on the results of the experiment, it is concluded that in handheld measurements of the intensity, the errors are two times larger compared to the robot measurement. The maximum error value for repeated measurements using a robot was about 1 dB, which is a consequence of factors that do not depend on positioning. In the case of manual measurement, the maximum error value in relation to automated robot measurement is 2.5 dB. Comparing the differences in the measured intensity in the case of the automated and the manual measurement, it is concluded that the manual measurement has a measurement error of 1.5 dB for individual measurement points.

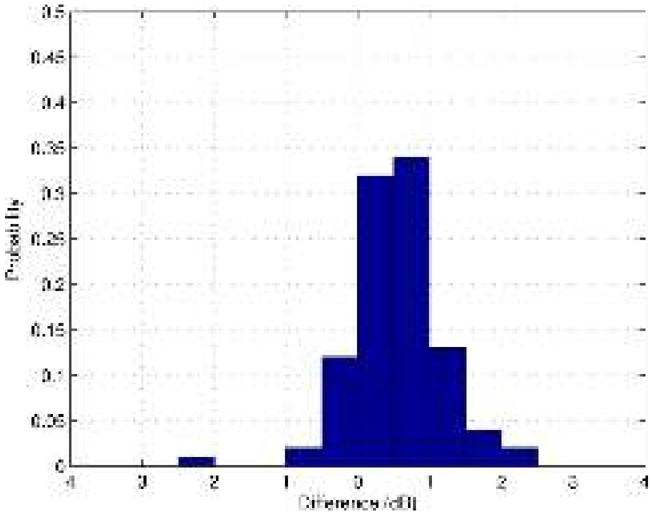


Fig. 7 Normalized histograms of the differences between repeated measurements with the robot and by Person 1

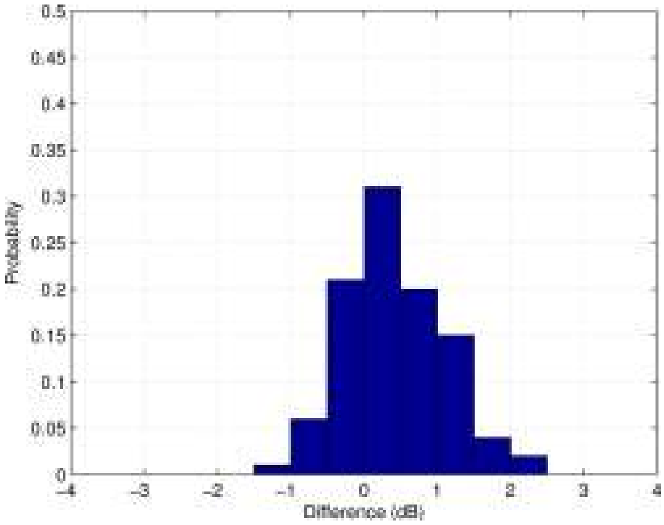


Fig. 8 Normalized histograms of the differences between repeated measurements with the robot and by Person 2.

In order to see the deviations between the repeated measurements with the manual positioning of the probe, more handheld measurements were made for both subjects who were measuring. In Fig. 9 and Fig. 10, are shown normalized histograms of the differences between repeated measurements carried out by Person 1 and Person 2, respectively. In repeated measurements carried out by Person 1, deviations are over 2 dB at the individual measurement points. This means that an error of about 1 dB is introduced due to the incorrect positioning of the probe during repeated measurements. The standard deviation for this experiment is two times higher than in the experiment when the repeated measurement was performed using a robot.

In the case of repeated measurements performed by Person 2, deviations of up to 6 dB in individual measurement points are observed. This value represents a large deviation, but the occurrence of such deviations is low in probability. A small value of probability means that this deviation occurred in a small number of measurement points. In this experiment, standard deviation has the highest value for all the experiments shown in this paper.

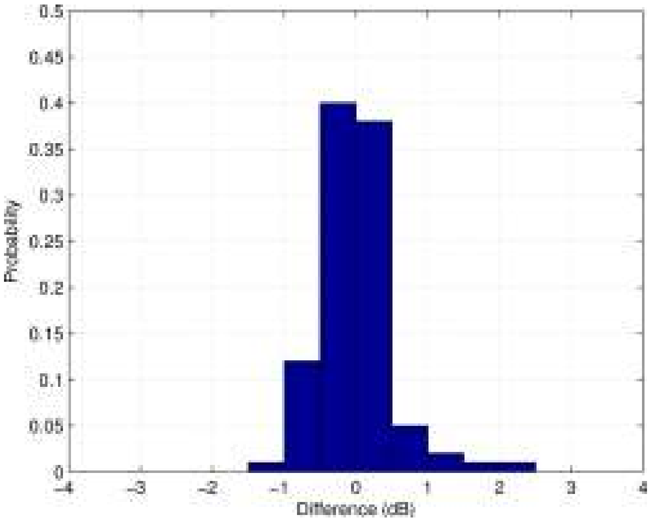


Fig. 9 Normalized histogram of the differences between the two repeated measurements performed by Person 1.

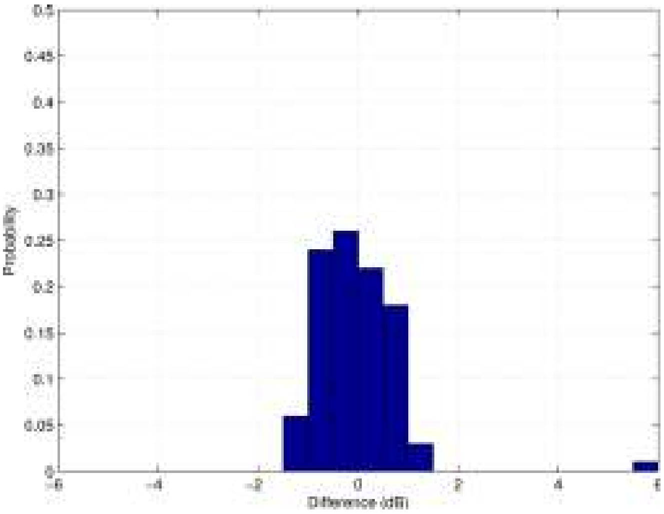


Fig. 10 Normalized histogram of the differences between the two repeated measurements performed by Person 2.

Fig. 11 shows a normalized histogram of the intensity difference for two measurements, one performed by Person 1 and another by Person 2. The aim of this experiment is to examine the differences which can occur when different people measure sound intensity of the same sound source. The obtained results show that the maximum deviations are about 2 dB. The standard deviation for this experiment is greater than the standard deviation obtained with the robot experiment, but it is comparable with the values obtained for repeated measurements performed by the same person. This means that the expected errors in repeated measurements do not differ significantly, regardless of whether the same or different person is repeating the measurement. There are differences between measurements made by different people, but their value is not large.

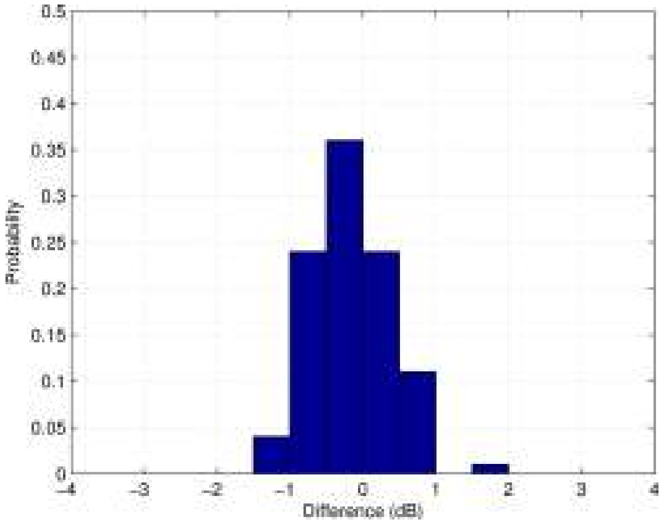


Fig. 11 Normalized histograms of the differences between repeated measurements performed by Person 1 and Person 2.

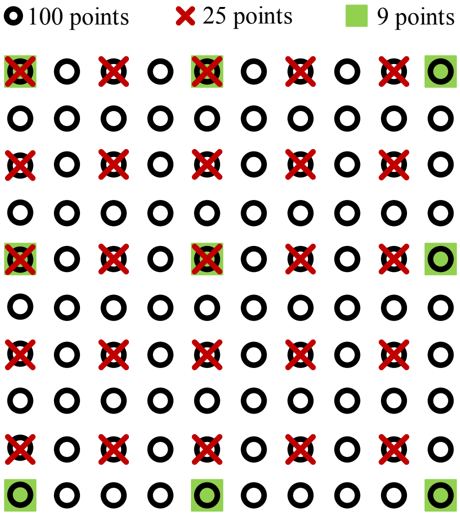


Fig. 12 The grid with 100, 25 and 9 measurement points on the surface of the DML speaker.

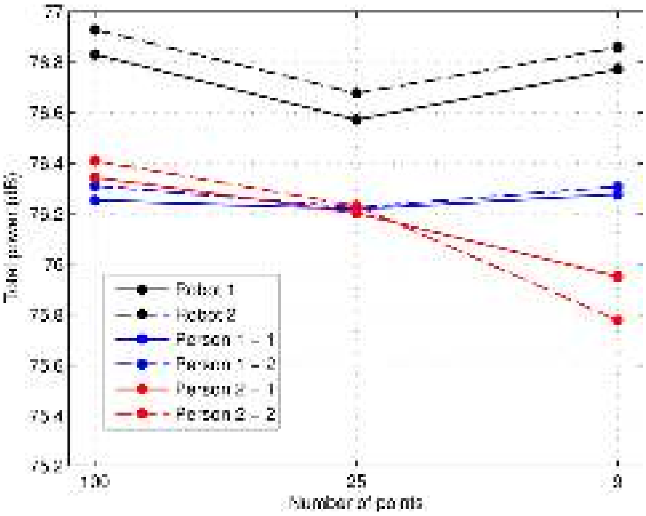


Fig. 13 The total sound power of the sound source calculated on the basis of three different grids of measurement points in 6 experiments.

Based on the sound intensity value measured at 100 measurement points and the equation (12), the sound power level of the analyzed DML loudspeaker can be calculated. For the calculation of the total sound power of the source, i.e. the sound power level, two measurements were performed using the robot, two measurements manually by Person 1 and two measurements by Person 2. These measurements were selected to investigate the effect of automated and manual intensity measurements on the total value of the power of the analyzed sound source [17].

The number of measurement points in the realized experiments is 100. However, based on expression (12), it is concluded that when calculating the total sound power, all the measurement points do not have to be taken into account, as the result is scaled with the number of points. In order to see the dependence of total sound power values on the number of measurement points, the number of measurement points was varied. It was selected to analyze the value of total power calculated from: 100 points (all measurement points), 25 measurement points, or 9 measurement points. In order to obtain measurements with 25 and 9 measurement points no additional experiments were performed. Instead, some points were excluded from the results of the experiments carried out with 100 measurement points. The points were chosen to be at an equidistant distance and the surface of the DML speaker was covered along the edges and where the mechanical exciter was positioned. The positions of the measurement points are shown in Fig. 12. The case with 100 measurement points corresponds to a case with a dense network of points, i.e. a good spatial resolution has been achieved. The situation in which the total sound power is calculated on the basis of 25 measurement points represents a relatively low spatial resolution. The worst spatial resolution was achieved in a situation with 9 measurement points.

In Fig. 13, the results of the sound power calculation for six different experiments and three different numbers of measurement points used for computation are shown. It can be seen from the picture that slightly lower levels of sound power are obtained in experiments where people manually positioned the intensity probe in the space. Comparing the results of the obtained sound power with 100 measurement points in which the sound intensity is measured, it is concluded that the values differ by about 0.7 dB. In comparison to the value of the total sound power, the difference obtained represents a very slight deviation. On the basis of this, it is concluded that in the case of the automated and the manual measurement of the intensity, there is almost no difference in the total sound power of the source calculated from the intensity value and the known surface area.

Observing the case with 25 measurement points used to calculate the sound power level, it is noticed that the differences between the individual measurements are still small and with the values of about 0.5 dB. By reducing the number of measurement points, a smaller difference in the individual measurements was obtained, but this is not a general conclusion because the deviation values depend on the dominance of the spatial distribution of intensity per surface and the choice of measurement points. In the case of 9 measurement points, the difference in the calculated values of the sound power level for individual measurements deviate about 1 dB, which is a greater deviation compared to the previous two analyzed cases. The lowest values of the sound power level were obtained for the experiments in which the intensity measurements were performed by Person 2, while the highest values were obtained for experiments in which the measurement was performed using the robot. Observing the curve for three different numbers of measurement points and two measurements using a robot, it is concluded that the differences in the sound power level for the corresponding grids are the same. On the basis of this, it can also be concluded that the use of robot has significantly improved repeatability in measurements compared to measurements made by hand.

The obtained differences for three different numbers of measurement points indicate that the deviation values between the automated and manual intensity measurements are very small compared to the total sound power of the source. This means that if the aim of the intensity measurement is to calculate the total sound power, there are no major differences between the robot measurement and the manual measurement. In such situations, increasing the number of measurement points does not necessarily lead to an increase in the accuracy of the calculated total sound power. However, when the goal is to look at the spatial distribution of the intensity of a sound source, the differences that can occur at individual points in manual measurements are up to 6 dB, which is a large deviation. In such situations, the use of robot gives a significantly higher accuracy of the intensity measurements. It should be noted that in the experiments with manual intensity measurement a cardboard stopper was used, which ensured the equal distance of the probe from the measurement surface. In practice, it is usual to measure without this stopper, so the results of the deviation in the total sound power, and also in the repeated measurements of the sound intensity would be greater.

One of the important aspects of using a robot to measure the intensity of sound is the time it takes to measure. In the analyzed experiments, the measurement was performed in 100 points, with the probe holding at one point for 4 seconds. When moving from one point to another, the robot takes about 2 seconds. Based on this, the total time required for the realization of the experiment is about 600 seconds, or 10 minutes. When the intensity measurements were performed by Persons 1 and 2, the time required to realize the experiment was significantly higher than the automated robot measurement. The probe holding time at one measurement point is the same as in a robot experiment, 4 seconds. However, when moving the probe from one measurement point to another, more time is required compared to using the robot. The time of positioning at the appropriate measurement point increases as the measurement progresses because of the man's fatigue, so resting is necessary during the measurement. The experiment was attended by two persons, one of whom had experience with such measurements (Person 1). In the case of Person 1, the time required to carry out such an experiment is about 30 minutes, while in the case of the Person 2 necessary time was about 40 minutes. Based on this, it can be concluded that robot usage leads to a large time saving in the intensity measurements. Time savings increase with an increase in the number of measurement points, as man becomes increasingly tired. Additionally, in such situations, a person cannot retain the exact position of the probe at the measuring point, so an error is introduced in the measurement results.

V. CONCLUSION

This paper presents the use of robots to measure the intensity of sound. The use of robots in this procedure simplifies the measurement process, which is difficult and time-consuming when measuring intensity manually. By using a robot, the duration of the measurement procedure decreases about 3 times in relation to manual measurements. The most important advantage of using a robot is the precision and repeatability of the probe positioning at the appropriate measurement points. It has been shown that the use of a robot when measuring the intensity, can reduce the error by 1 dB, compared to the case of manual positioning of the probe. Experiments have been carried out which show that when repeating the manual intensity measurement procedure, up to 6 dB differences can occur in individual measurement points, even if the measurement was performed by the same person. The demonstrated use of the robot certainly leads to an increase in the price of the apparatus required for the measurement, but it results in a significantly higher accuracy of the measurement and facilitates the measurement procedure. Therefore, in the cases where accuracy is important, the use of robots is justified. If the intensity measurement results are used to determine the total sound power of the source the deviation between manual measurement and robot measurement are very small compared to the total sound power value. In such situations, using a robot does not achieve a significant improvement in accuracy.

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Nikola Knežević was born in Kraljevo, Serbia, in 1993. He received his Bachelor degree in electrical engineering from the University of Belgrade, School of Electrical Engineering, Belgrade Serbia, in 2016. In 2013, he joined the Faculty of Electrical Engineering at the University of Belgrade. Currently, he is a Teaching Associate at the University of Belgrade, School of Electrical Engineering. His research interests are robotics, mobile robots, industrial automatization, sensors in robotics and others robotics topics.

Miloš R. Bjelić was born in Priboj, Serbia, in 1989. He received the Bachelor degree in electrical engineering from the University of Belgrade, School of Electrical Engineering, Belgrade, Serbia, in 2012, and the M.Sc. and Ph.D. degrees in electrical engineering from the University of Belgrade, Belgrade, Serbia, in 2013 and 2018, respectively. In 2013, he joined the Faculty of Electrical Engineering at the University of Belgrade. Currently, he is a Teaching and Research Assistant at the University of Belgrade, School of Electrical Engineering. His research interests are in audio systems, electroacoustics, room acoustics, digital signal processing, space-time signal processing, microphone array, sound insulation, physical and technical measuremen.

Kosta Jovanović received his dipl.ing. and M.Sc. degree in electrical engineering in 2009 and 2010 and Ph.D. in robotics in 2016. He is Assistant Professor in robotics at University of Belgrade - School of Electrical Engineering. His research interests are human-robot interaction, humanoid robots, and variable compliant actuators. He was visiting researcher at Technical University of Munich and DLR Institute of Robotics and Mechatronics in Germany. He has already published more than 20 papers which are cited more than 170 times with h-index=7 (source: Scopus) and participated in several national, EU funded FP7 and H2020 projects. He was awarded by University of Belgrade, City of Belgrade, Nikola Tesla Foundation, and German Academic Exchange Service (DAAD) for its research activities.