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Technical Note

Automated Measurement System for Room Acoustics – an Initial Feasibility Study

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Currently used procedures in room acoustics measurements are not automated. Particularly in medium-sized and large areas they require a lot of time and intensive labour which directly translates into an increase in the measurement cost. Introduction of an automated system would increase efficiency of the measurements, and therefore could present both practical and scientific benefit. The paper presents initial feasibility study for designing a system that permits the measurement of selected acoustic parameters for any choice of three-dimensional grid of measurement points throughout the volume of the room. The system will utilize an autonomous probe attached to a blimp, and will be able to measure and analyze acoustic characteristics of the rooms. The article discusses the initial choices of the system elements, starting from the general idea, through the mechanical design and control procedures, the software that controls positioning and flying of the probe, up to the automation of the measurement procedure and its possible impact on the acoustic field.

Keywords: acoustic measurement, room acoustics, automated measurement system.

1. Introduction

The idea behind the construction of an autonomous system for the measurement and analysis of the acoustic properties of a room is based on the experience of engineering teams performing acoustic measurements within contracted studies or a research conducted at the Department of Mechanics and Vibroacoustics, AGH UST Kraków.

The main problem faced by researchers is a large amount of time and effort during room acoustics study, especially in a large volume spaces. In some cases one of the research methods are surveys that include questions concerning, inter alia, transparency, clarity and intelligibility of sound, reverberation and the volume, the impression of spaciousness of a room or a stage. The assessment of audience in this study is subjective.

Objective evaluation involves measurements of acoustic parameters and is based on ISO 3382-1:2009. The method utilizes integration of impulse response with flat spectrum excitation, i. e. sweep sine or pseudo-random maximum length sequence (MLS) (Kamisiński, 2012; Kutruff, 2009). The measurement is carried out at selected points of the room. The movement of the microphone, recording, and description of the samples is a very time-consuming process. It is particularly so when the measurement is carried out by a small team.

Data obtained during the measurements allows to determine acoustic parameters such as reverberation time (RT), early decay time (EDT), clarity (C80), sound strength (G), definition (D), speech transmission index (STI), bass ratio (BR), treble ratio (TR), and stage support (ST).

The last stage of the room assessment is the simulation of the acoustic field inside it using a specialized software (Pilch, 2014; Gołaś, 2010). It allows to evaluate acoustic parameters under various conditions, e.g. with a room fill or with proposed acoustic adaptation.

On the basis of the measurements results, the results obtained from the simulations, and in some cases the results of the survey (Bech, 2006), adjustments are proposed for the existing room (Kamisiński, 2010) and an appropriate room adaptation is suggested. It is vital that the results of both methods, experimental and simulation, applied for the same room are compatible. If the room is particularly difficult to model it would be a good practice to increase the number of measurement points.

While analyzing the process of studying the acoustic quality of the room, it was concluded that the increase of number of measurement points would bring benefits. However, to do so, it is necessary to automate the measurement process. Automation, and therefore exclusion of human operator from most parts of the process, shall (Badźmirowski, 1979; Sowiński, 1976) increase the effectiveness of the operations performed, and eliminate the mistakes of the human operator. The measurement systems can be distinguished by the degree of process automation, i.e. hand control systems, semi-automated systems, and automated systems. The solution for the automation of the acoustic measurement process in confined spaces proposed in this paper should allow for all of the above variants. Depending on the study, it may be necessary to perform efficient, fully automatic measurement as well as measurement with excitation controlled by the operator – in non-typical cases.

Systems for acoustic measurement automation implemented so far were meant mainly for laboratory rooms with constricted work space (Felis, 2012). Moreover, such systems serve a different purpose – they are used for measurement of acoustic properties of the object introduced into a room (in this particular case – an anechoic chamber), and not of the room itself. There is also a concept of an aerostat for noise measurements outdoors (Rudno-Rudziński, 2004). It introduces an idea of using a microphone attached to a balloon instead of the one mounted on a stand. The idea does not involve automation nor an autonomous movement of the balloon probe. It aims mostly at taking measurements in higher altitude points outdoors. However, there are problems with stability of such a probe outdoors as a balloon is susceptible to meteorological conditions, particularly wind.

Instead of a balloon, one could use a blimp to gain a control over a probe position in three dimensions. There are many ready to use radio-controlled blimps. Such blimps were used for testing navigation control techniques (Gonzalez, 2008) or visual control over an autonomous aerial vehicle (Alkurdi, 2012).

All of the aforementioned solutions could be of some help for a team carrying out room acoustics measurements. However, according to the knowledge of the authors of this paper, there is no ready to use automatic solution developed precisely for this purpose. That is why an idea was developed to create a system that would allow to automatically carry out measurements of selected acoustic parameters for any choice of three-dimensional grid of measurement points throughout the volume of the room, by the means of autonomous probe attached to a blimp.

In order to develop such a system, a number of decisions regarding its components, control methods, and utilized algorithms must be made. They are presented in this paper as follows. The second section discusses general concept of the system. In the third section operation of the system is presented, including movement, control, and navigation of the blimp, as well as measurement process performed automatically by the probe. An aerial vehicle can have some effect on the acoustic measurement results obtained by the probe attached to it, which is discussed in the fourth section. Finally, fifth section of the paper presents a summary and conclusion.

2. The concept of the system

2.1. Design assumptions

Considering limitations of solutions and methods currently used in acoustic measurements, and aiming at designing a system surpassing some of those limitations, the following design guidelines were assumed:

- total flight time of the probe: 60 min,
- the ability to hover freely,
- wireless transmission of measurement data from the probe to the base,
- possibility to enter a predefined trajectory for the probe,
- fully autonomous operation that does not require human operator control,
- low weight, resistance to damage,
- small footprint (the ability to maneuver in tight spaces).

Some requirements implemented by the system are more important, as shown in Table 1 by assigning appropriate numerical values.

Table 1. Summary of the project guidelines with the importance ratios: 1 – the least important, 5 – the most important.

Requirement	Importance ratio
Autonomy	4
Data processing	2
Communication	4
Load capacity	1
Controllability	5
Hover capability	5
Real-time data transmission	2
Small size	4

There are various types of unmanned aerial vehicles, however, only aerostat meets the requirements posted in the project. The main reason for disqualifying solutions such as rotorcraft, aircraft and flapping wing is their inability to freely hover in the air in order to carry out measurement in single point, that is with engine shut down, as otherwise it might become an additional audio source.

2.2. General structure of the system

The goal of the system is to automate not only the measurement cycle in a single measuring point, but also the movement of the probe between the points. Such a system needs at least two units (Fig. 1): the probe (mobile, attached to a blimp) and the base (stationary). The base unit, equipped with a computer, collects measurements results and stores them within a database system. The same unit is also utilized to prepare input information, such as a map of the room, or distribution of the measurement points. Using information about the room and measurement points, and complementing it with a localization feedback from the probe, the base calculates navigation data and sends appropriate control signals to the probe. The task of the probe is to achieve preset position, then initiate the measurement process followed by a transfer of recorded data to the base unit using the transmission module.

The base unit consists of elements used in room acoustics measurements and control elements. They include:

- omnidirectional source,
- power amplifier,
- audio interface,
- portable computer with increased resistance to external conditions,
- dedicated software,
- elements of the positioning system,
- elements of the data transmission system,
- autonomous power supply system.

The probe unit includes:

- remotely (wirelessly) controlled aerostat,
- data acquisition module (microphone, preamplifier, A/D converter),
- elements of the positioning system,
- elements of the data transmission system,
- batteries.

The structure of the measurement and control subsystem might be generalized as presented in Fig. 2.

A typical helium filled airship that could be used to carry the probe has a volume of 1.1 m^3 and load capacity of 150 g. If all unnecessary to carry parts of the system are transferred to the base unit, the use of the latest generation of electronic components, with reduced power demand, in combination with a lithium-polymer cells, should allow a reduction in weight of the systems mounted on the blimp, and thus the use of the airship with a smaller volume.

The use of a blimp will allow the probe to hover silently during measurements, with motors disabled. It should be possible in rooms, where no wind is present. Three electric motors with propellers will help to move the probe between measurement points, and to stabilize it before the measurement. The position and stability will be confirmed by the navigation system. After the confirmation, motors and all unnecessary systems will be powered down for the period of measurement.

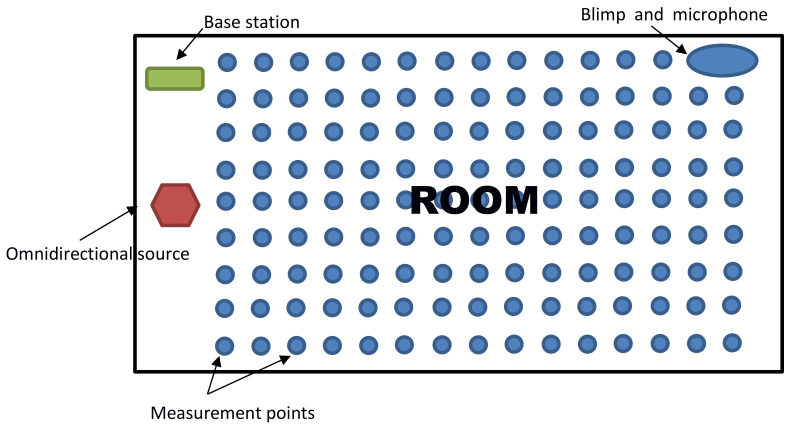

Fig. 1. General scheme of operation of the system.

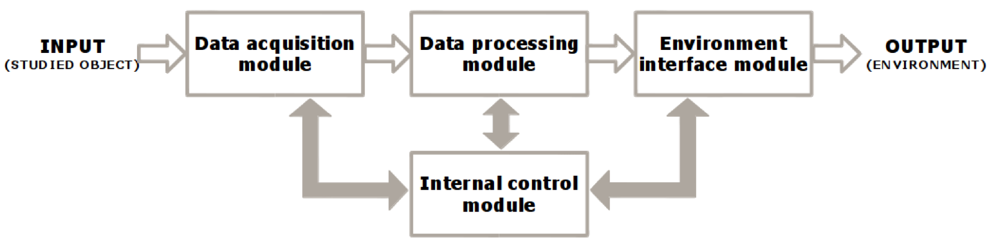

Fig. 2. The structure of the measurement and control subsystem.

3. Movement, control and operation of the system

3.1. Motors

In order to be able to move in all directions, the probe will have to use three motors (Fig. 3). Currently, the most commonly used in model-making are brushless DC (BLDC) motors. The torque generated by a typical BLDC motor is given by the following formula (Hoffman, 2010):

$$\tau = K_t(I - I_0), \tag{1}$$

where τ – total torque, I – input current, I_0 – no load current, K_t – constant.

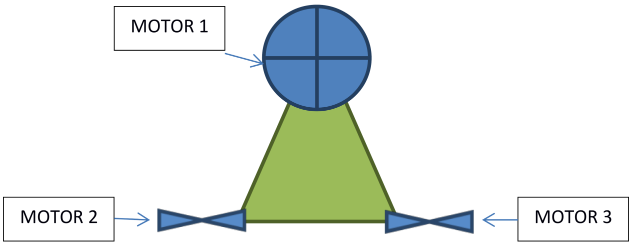

Fig. 3. Placement of drive units in the gondola of the blimp.

The total voltage on the motor is a sum of the electromotive force and loss (Hoffman, 2007):

$$V = IR_m + K_v\omega, \tag{2}$$

where V – voltage on the motor, R_m – motor resistance, ω – angular velocity of the motor, K_v – constant dependent of the electromotive force generated by the rotations of motor per minute.

The total power of the motor is given by (Hoffman, 2007):

$$P = IV = \frac{(\tau + K_t I_0)(K_t I_0 R_m + \tau R_m + K_t K_v \omega)}{K_t^2}. \tag{3}$$

During the initial design phase the resistance of the motor R_m can be omitted, so the power is proportional to the angular velocity (Himanshu, 2012):

$$P \approx \frac{(\tau + K_t I_0)K_v}{K_t}\omega. \tag{4}$$

With the assumption that $\tau \gg K_t I_0$, which is satisfied since the considered motor is without load, the torque is small. In practice such approximation of the model is close enough, and the power may be expressed as:

$$P \approx \frac{K_v}{K_t}\omega. \tag{5}$$

Controlling the flight trajectory is made by controlling the torque on the motors.

With motors arranged as shown in Fig. 3, Table 2 illustrates how to change the rotational speed of motors to move the aerostat in desired trajectory.

Table 2. Configuration of motors depending on the movement direction.

	Motor 1	Motor 2	Motor 3
Z +	+	0	0
Z –	–	0	0
X left	0	–	+
X right	0	+	–
Y forward	0	+	+
Y backward	0	–	–

If the resultant force is not equal to 0, aerostat will move. The amount of energy produced in time is equal to the force generated on the propeller, which caused its movement on the distance x.

$$P\,\mathrm{d}t = F\,\mathrm{d}x. \tag{6}$$

So that the power:

$$P = F\frac{\mathrm{d}x}{\mathrm{d}t} = Tv_h, \tag{7}$$

where T – torque, v_h – air velocity.

It is assumed here, that the medium (air) is stationary due to the fact that the measurements will be conducted in confined spaces, and hence, its velocity is 0. That leads to the dependence of air velocity on thrust (Himanshu, 2012):

$$v_h = \sqrt{\frac{T}{2\rho A}}, \tag{8}$$

where ρ – density of the medium (air), A – area of rotating propeller.

Using the formula for power it can be stated that:

$$P \approx \frac{K_v}{K_t}M_s\omega = \frac{K_v K_\tau}{K_t}T\omega = \frac{T^{3/2}}{\sqrt{2\rho S}}. \tag{9}$$

In general, the torque $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$. In the discussed case the torque τ is proportional to the thrust T, and the proportional ratio is constant K_τ, which depends on the configuration of the propellers and their parameters. Solving the above equation for T we obtain (Hoffman, 2007):

$$T = \left(\frac{K_v K_\tau \sqrt{2\rho S}}{K_t}\omega\right)^2 = k\omega^2, \tag{10}$$

where k – constant.

Finally, the thrust is expressed by:

$$T_B = \sum_{i=1}^{4} T_i = k\begin{bmatrix} 0 \\ 0 \\ \Sigma\omega_i^2 \end{bmatrix}. \tag{11}$$

3.2. Flight control unit

To control movement of the probe Arduino, an arithmetic logic unit, has been selected. It is a platform based on a simple Open Hardware project designed for microcontrollers built on a single printed circuit board with built-in I/O and standardized programming language. Arduino programming language is based on Processing environment and C/C++ (Arduino Due, 2013).

Currently, in the official palette of Arduinos' manufacturer there are 19 versions of the platform available. Most of them work on the ATmega microcontroller units (MCUs), except for model Due, and two new models (Zero and Tre), all of which utilize either 32-bit ARM MCUs, or combination of ATmega and ARM. Number of digital inputs depends on the type and purpose and according to the manufacturer varies from 9 to 54. There is also a maximum of 16 analog inputs that can be utilized, e.g. for control.

The following criteria have been taken into account when selecting the hardware platform: available memory, processor frequency and the possibilities of development, and the main one – weight of the unit. There are three options considered at the moment.

First, Tiny Duino unit is characterized by small size, the same computing power as its larger counterparts, and has a number of peripherals available in a mini version. Optionally, depending on the final demand for the processing power and 32-bit capabilities, Arduino Due or Tre are considered. Tre is the most capable, but is the largest of the three, and will increase the demands on the lift from the blimp.

Tasks of the control unit are to perform logical and arithmetic operations, the pre-processing of data, communication with the base and monitoring of the system state. It is therefore necessary to equip the aerostat with the sensors system that consists of:

- gyroscope,
- accelerometer,
- barometer,
- ultrasound distance sensor,
- magnetometer,
- elements of positioning system for confined spaces.

Such equipped system allows a precise movement in the measurement environment and automation of the measurement process.

3.3. Flight control method

The system is supposed to perform the work without a human operator supervision. The aerostat that carries a measurement probe will be equipped with the module using PID controller (Proportional Integral Derivative) to efficiently control its movement (LED Zeppelin Overview, 2014). The PID control algorithm uses three values: proportional, depending on a present error, integral, depending on past errors, and derivative, that is a prediction of future errors. The values are weighted and summed to adjust controlled process.

In the case of aerostat the proportional component of the PID controller (K_p) is an information about the location. The higher the value of K_p, the better the response to the change of engine. However, if the value K_p is too high, it may result in exceeding the preset position and the force will work again, this time in an opposing direction. As a result, the aerostat may perform oscillating movements to regain stability. When the value K_p drops, steering of the airship becomes difficult up to the point, where the value falls below the minimum value for proportional element (the threshold value), which results in total loss of stability. Too low value leads to long times needed to perform desired maneuvers.

Integral component is given by the transmittance (Kowal, 2006):

$$G_r(s) = \frac{1}{T_i s}. \qquad (12)$$

It defines the force necessary to maintain the position. Its value increases with the duration of the deviations from the initial position. The higher the value of the integral component, the better the system retains the desired position and increases the delay in returning to the starting position. With the increase of the integral component value proportional component K_p is significantly reduced. Reducing the value of the integral component improves system's response in returning to the starting position, but reduces the ability to maintain position.

Application of PID controllers leads to a good compromise between the ability to precisely maintain the position at the measurement point, and the probe movement velocity. A stability study will have to be performed with a prototype in various scenarios. It will allow to set PID controller values, or even skip one of the components (probably integral) in some usage scenarios. In this way the system can be adapted to various room sizes, considering desired trajectory and desired measuring point localization precision.

3.4. Measurement process

In order to control the measurement process a software system has been developed. Its main objective is to control a set of two satellites and a base. The base is meant to control actions of the satellites. One satellite is responsible for reproducing audio signal (e.g. sweep sine) sent from the base using omnidirectional source. By default it will be a part of the base unit, but can be detached, if necessary. The other satellite does the actual measurement, that is essentially recording, and it will be a part of the probe. Devices need internal memory to collect data. Recording can be sent on the fly, or after the measurement, on the request from the base. The diagram of the solution is shown in Fig. 4.

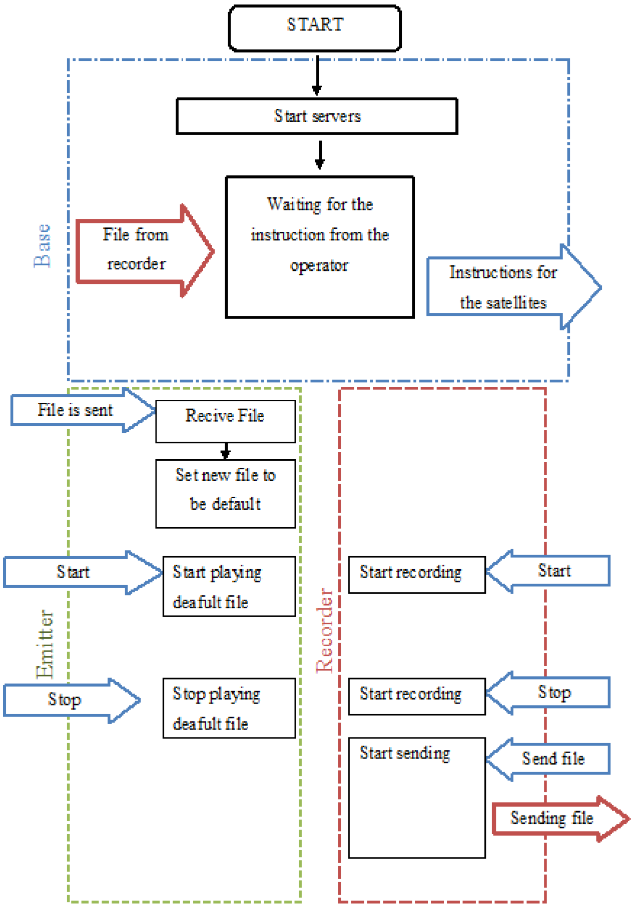

Fig. 4. Diagram of the measurement control software.

The base works as a server for data transmission (Fig. 5) and handles the main user interface. An operator is able to manually control servers, reproduce sound samples, conduct measurements, and view the results, or run chosen automatic program. The base is responsible for data transfer and is the place where measurement data is stored with all the accompanying data handled by a database software.

A recording satellite is responsible for recording (Huber, 2005) and sending acquired data back to the base. Recording can be triggered automatically when a condition is met (e.g. measurement point has been reached by the probe) or it can be triggered manually by the operator. A reproducing satellite is responsible for emitting signals received from the base.

Once acquired, data can be analyzed and results (selected parameters) displayed "on the fly". The whole software system is modular and created with open source tools (e.g. Qt toolkit for the user interface and data transmission, FFTW library for spectral analysis, PHP for database interface). Modularity and openness makes the system easy to upgrade, easy to modify, and flexible, to enable the use of various measurement methods and to be able to adapt to changing conditions (e.g. different environments than closed rooms).

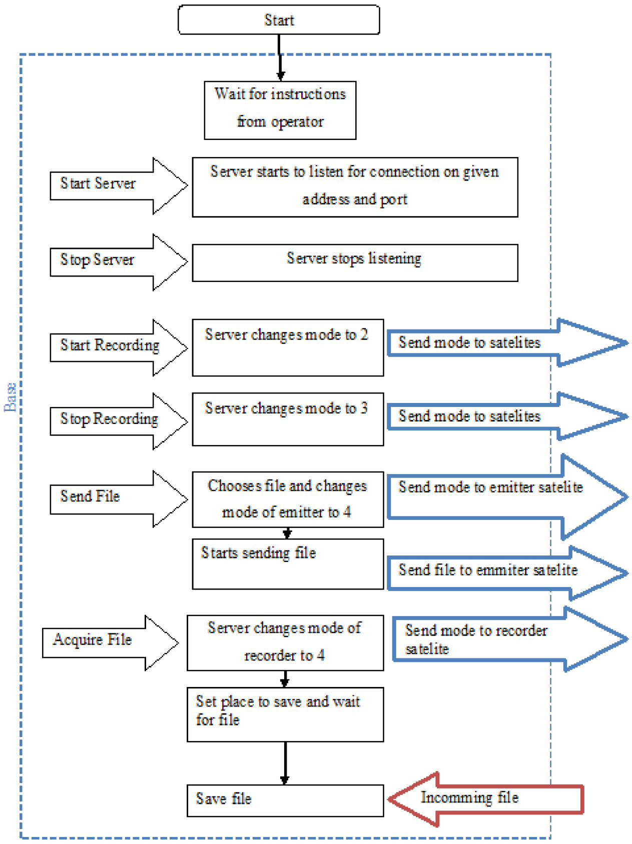

Fig. 5. Base software diagram.

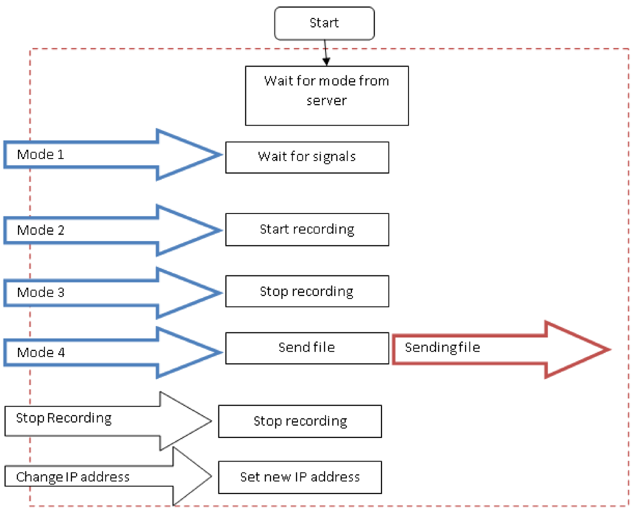

Fig. 6. Recording satellite diagram.

3.5. Navigation and operation of the system

The system operation includes three stages:

Stage I:

- the introduction of the digital map of the room, e.g. as DXF file,

- the imposition of grid of measurement points,
- determination of the trajectory of the probe;

Stage II:

- control,
- positioning,
- measurement,
- data transmission;

Step III

- calculations,
- plotting a map of the results,
- preparation of a report on the measurement.

In this section the process of preparing the room's map and determination of the trajectory are presented. The details of stages II and III were discussed in previous work (Borkowski, 2011). As mentioned in Subsec. 3.3, movement will be controlled using PID algorithm. A real-time locating system (RTLS) will be used for the navigation and positioning. To obtain high resolution of positioning (0.15 m) RTLS will be based on two types of information: angle of arrival and time-difference of arrival of ultra-wideband (UWB) radio signals (6–8.5 GHz). It will use two types of hardware components: labels emitting UWBs (on localized objects, in this case a probe and a sound source) and sensors.

In order to properly interpret 3-dimensional trajectory and environment description in a popular DXF format, a software that can decode commands such as “point”, “line”, “circle” and “poliline3D” has been created. The sequence of input elements in DXF file is important, because figures are stored in the order they are entered. Thanks to that property the algorithm can connect polylines into one. When provided with starting and ending points, the resulting polyline begins its course in the first point introduced and ends in the second one, creating a trajectory. The outlines of environment objects and surroundings are made by means of lines and circles; other figures are skipped.

For testing purpose a reference model has been created in AutoCAD 2012. Map in Fig. 7 shows a schematic plan of the environment in which the trajectory is outlined. It consists of a white environment elements (created out of lines and circles) and fragments of the trajectory (drawn with 3D polylines), for demonstration marked in purple. Enlarged pictorial points mark the starting and the ending point. Figure 8 shows a consecutive displayed items [xyz] building up the polyline trajectory. An array of coordinates is related to the measurement points. This information is sent to the module responsible for the movement control.

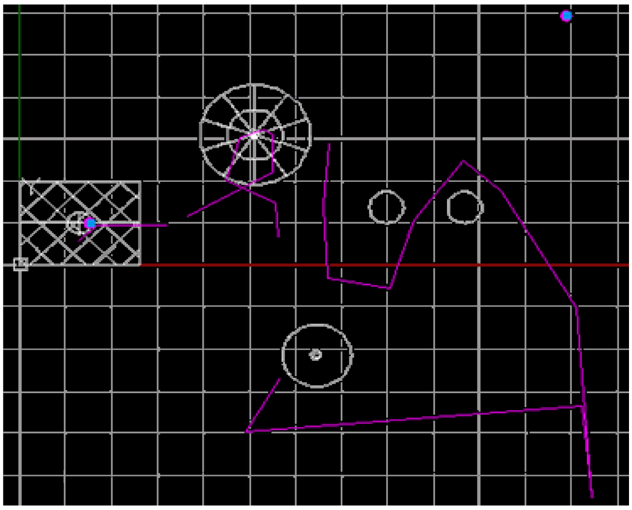

Fig. 7. The view from above on the environment with a trajectory (AutoCAD 2011).

TRAJECTORY:

1.0e+004 *

0.1901	0.1250	0
0.1876	0.0978	0.0364
0.1611	0.0733	0.0727
0.2111	0.1197	0.1134
0.2727	0.1197	0.1536
0.3988	0.1197	0.1470
0.4567	0.1461	0.1268
0.6860	0.2743	0.0966
0.6862	0.3863	0.0969
0.6664	0.4047	0.1181
0.6005	0.3798	0.1232
0.5597	0.2536	0.0722
0.6971	0.1851	0.0776
0.7018	0.0857	0.1057
0.7086	-0.3385	0.0627
0.6154	-0.4945	0.0619
1.5286	-0.4183	0.0630
1.5562	-0.6924	0.4610
1.5124	-0.1291	0.0946
1.3102	0.2180	0.0328
1.2060	0.3119	0.0151
1.0735	0.1343	0
1.0051	-0.0680	0.0146
0.8372	-0.0380	0.0134
0.8269	0.1795	0.0200
0.8402	0.3590	0.0865
1.4858	0.7410	0

Fig. 8. The result of the algorithm – the positions of the trajectory.

4. Some possible impacts of the properties of the system on the measurement process

4.1. The effect of the aerostat on the acoustic measurement results

Since the dimensions of the measurement probe exceed 1 m^3, its impact on the reverberation time in studied room should be considered. Building a reliable model of the room with the "balloon" located inside requires the use of FEM. This is related to taking into account the coupling between the sound pressure changes in two centers with different physical parameters and vibration of the balloon's shell (Filipek, 2008). Additional computational complexity is introduced by necessity to take into account the initial stresses in the shell of the balloon. The biggest drawback of the use of this type of FEM is that the large size and high frequency space is computationally very expensive. In this case, to ensure a minimum number of elements to a wavelength (4 for the shape of the parabolic function) it would be necessary to determine the highest frequency present at about 500–1000 Hz. The full-band calculations are unjustified. However, with measurement results, one can try to build such a model in low frequencies (e.g. 250–500 Hz) (Gołaś, 2009).

To measure the effect of the system on the room, the Laboratory of Technical Acoustics reverberation chamber in the Department of Mechanics and Vibroacoustics was used. Measurement and calculation of the sound absorption was carried out according to PN-EN ISO 354:2005. Reverberation time of an empty chamber and with the sample (3 balloons) was determined by integration of the impulse response using B&K 7841 Dirac 5.0 software. Table 3 shows the physical properties of the measurement environment.

Table 3. Measurement environment properties.

Temperature with sample t [°C]:	23.6
Temperature without sample t [°C]:	23.6
Relative humidity with sample h [%]:	43.6
Relative humidity without sample h [%]:	43.7
Number of measurement points:	12
Number of diffusive elements:	5
Volume of the reverberation chamber [m^3]:	180.4
Total area of the chamber [m^2]:	193.6

Table 4 presents the results of measurements of sound absorption for a membrane system, and for comparative purposes by human.

For balloons hung absorption at high frequencies turned out to be negative, but in this band the values are small and likely to arise from fluctuations in humidity of the environment. To obtain more accurate results it will be necessary to repeat the measurement using finished probe in laboratory as well as under real conditions.

Table 4. Sound absorption for a membrane system and for a human.

Hz	Sound absorption [m^2]		
	Balloon on the floor	Balloon hung	Human
100	0.40	0.32	0.05
125	0.51	0.35	0.06
160	0.44	0.37	0.1
200	0.06	0.05	0.14
250	0.16	0.13	0.15
315	0.15	0.10	0.16
400	0.13	0.11	0.23
500	0.11	0.08	0.32
630	0.09	0.07	0.43
800	0.06	0.03	0.59
1000	0.08	0.08	0.69
1250	0.06	0.08	0.77
1600	0.14	0.16	0.84
2000	0.09	0.09	0.88
2500	0.21	0.19	0.91
3150	0.25	0.03	0.89
4000	0.15	0.17	0.79
5000	0.40	0.37	0.69

What is important, comparing the results obtained with the membrane systems to a human acoustic absorption, it can be concluded that for the higher frequencies (above 200 Hz) membrane systems display better properties, while in low frequencies they are slightly worse than a human.

4.2. The effect of the movement of the probe on the acoustic measurement results

In order to start the measurement after the probe has reached the position, the microphone suspended from the blimp will require some time to stabilize and stop oscillating. The requirement of zero velocity for the microphone can be met either by introducing wait time period after the aerostat stops, or by calculating the appropriate speed curve during movement. Both solutions slow down measurements of the whole room, so the possibility of performing the measurement with non-zero velocity is worth considering.

To measure the impact of a non-zero microphone velocity on the results, the Laboratory of Technical

Acoustics reverberation chamber in the Department of Mechanics and Vibroacoustics was used. Measurement and calculation of T20 and EDT parameters were carried out using B&K 7841 Dirac 5.0 software. Two types of excitation signals were used: sweep sine (10.9 s) and MLS.

Two situations were compared: immobile microphone on the stand (the reference), and the same microphone in slow circular motion on the rotary table (Fig. 9). Even when the microphone was not moving, the table was rotating in order to maintain the same conditions in both situations (background noise). The table did one revolution per minute, so, considering values given in Fig. 9, linear velocity of the microphone was $1.6*10^{-2}$ m/s.

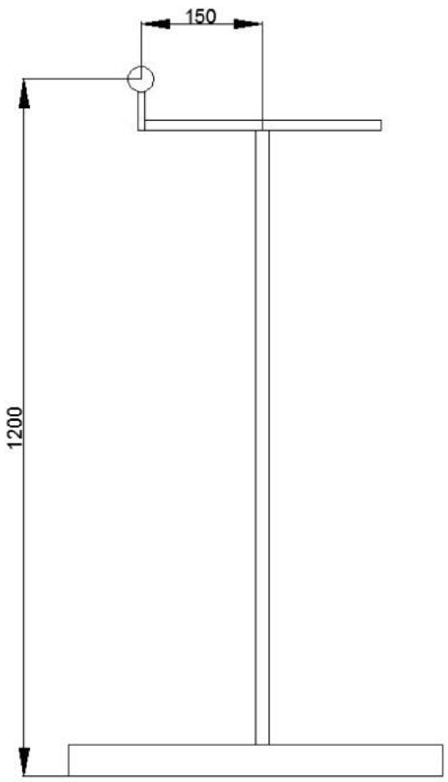

Fig. 9. Experimental setup – microphone on the rotary table (distances in millimeters).

The differences between mobile and immobile measurements in percentage of the reference value were calculated, and the results are presented in Table 5. In case of T20, errors caused by the movement of the microphone are small for the sweep sine signal, and larger for MLS. In case of EDT results are worse, but still not very large in all but a few frequencies (below 40 Hz, above 6300 Hz, and in 630 Hz). Considering those results, even when the microphone is not fully stabilized, some useful results can be obtained, allowing faster measurements (not requiring full-stop of the probe).

Table 5. Errors caused by microphone movement.

Frequency [Hz]	Error [%]			
	T20 Sweep sine	T20 MLS	EDT Sweep sine	EDT – MLS
100	1.21	3.67	0.58	2.21
125	0.10	0.27	1.68	1.31
160	0.26	0.00	1.41	0.64
200	0.75	1.52	4.46	4.60
250	0.48	0.21	0.78	1.29
315	2.21	2.47	4.59	4.59
400	1.05	1.31	2.66	2.56
500	6.39	2.43	5.41	3.43
630	5.59	6.02	14.11	13.68
800	7.52	7.39	3.29	3.16
1000	0.64	1.08	6.26	5.75
1250	0.45	2.23	6.94	5.47
1600	1.29	1.51	2.53	2.59
2000	0.65	2.02	4.76	0.73
2500	2.94	8.63	5.65	3.79
3150	0.24	14.59	2.62	1.17
4000	5.58	7.93	5.98	9.28
5000	5.58	6.48	0.21	5.03

5. Summary and conclusions

The most important advantage of using proposed automatic measurement system is the ability to gain a large number of measurements. It is possible to perform measurements in points unavailable to traditional microphone stands (higher altitudes) or in tight spaces. At the same time, the use of the system will significantly shorten the duration of the measurement, while maintaining similar effect of the measurement system on the result, as in the traditional measurement, performed by the operator with a microphone and a stand.

The design of the system allows it to be expanded with:

- more advanced analysis of the results (in the base unit),
- measurements of other (not just acoustical) parameters,
- compensation modules for the environment conditions (e.g. for measuring in a partially open space).

The system will be innovative – according to the knowledge of the authors, no similar solution exists. Its application will introduce more accurate and detailed measurements, and thus will bring advancements in the field of the room acoustics.

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