AURALIZATION OF SEVERAL CHURCHES AND LISTENING COMPARISON USING MULTIDIMENSIONAL SCALING APPROACH.

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ABSTRACT

Modern auralization techniques allow to make better assessment of particular interior type for different destination and purposes. The quality and reality of acoustic recording and reproduction systems increase so the results of this kind of research are much more reliable.
The article shows the psychoacoustic comparison of different reverberant interiors. The auralization was provided using 1st order ambisonics spatial impulse responses convoluted with anechoic choral music. Listening tests were conducted within the 16-channel sound system. The subjects were tested using the pair comparison method and the results were analyzed with the multidimensional scaling approach.

1. INTRODUCTION

Although there is an increase of popularity and diversity of modern auralization techniques, they are not very often employed in a room acoustics validation and evaluation. Early works on that subject were conducted using few channels sound systems with many simplifications [1], [2]. Modern ambisonics techniques [3], [4], sound-field synthesis [5] and other complex systems [6], [7] are well known and commonly exploited but hardly to previously mentioned goals. Actual work focuses on that subject with respect to orthodox churches, so on interiors, where the acoustics features are extremely important and connected with a sense of characteristic space. The chosen orthodox churches from the southern and eastern parts of Poland were examined in the context of the orthodox choral music. The Orthodox church (referred as a building) is inseparably connected with spirituality and philosophy of the eastern Christianity. Its architecture is based on orthodox liturgy and implicates a natural cultural landscape of the east part of Europe. The acoustic measurements in orthodox churches were marginalized by now and only a few buildings were examined.
The first order ambisonics is employed in a measurement process and in listening experiments. The article shows the research methodology and the main statistically developed results.

2. MEASUREMENTS OF SPATIAL IMPULSE RESPONSES IN THE CHOSEN ORTHODOX CHURCHES IN POLAND

Measurements of SIRs (Spatial Impulse Responses) were conducted in eleven chosen orthodox churches in Poland from June to October 2012.
The measurements and the overview of basic features were provided for the churches with different architecture style, size and interior design. In order to measure SIRs, EASERA Pro software was employed as well as authors algorithms implemented with the Matlab computing language. The ISO3382 standard [8] was followed during the measurements as possible. Due to the specific goals of the research, some simplifications were made. As it was mentioned before, first order ambisonics microphone - Soundfield ST350 was used, and instead of an omni-directional source, an active loudspeaker JBL EON 515 was employed. Because of the main destination of SIRs (listening experiments), the number of measurement locations was also limited. The main placement of the measurement instruments was common for all the churches. The sound source was placed in front of the iconostasis and the microphone behind a tetrapod. This is a typical place where a priest, a deacon sings or the choral music concerts take place. Behind the tetrapod (a small table about six meters in front of the iconostasis) there are the best first seats for the audience. On the basis of the B-format pressure component, the room acoustic parameters were also calculated and some of them are listed in table 1. Except for the previously explained setup, the measuring points were located at characteristic places for orthodox churches:

- in a central point of the church (at least at two different positions),
- under the main dome,
- under the gallery,
- at the back of the church,
- at a side naves (at least three different positions),
- at other positions if the church shape suggested this.

Except for the small local wooden churches at Zdynia and Konieczna, all of the churches were made of bricks. The most Latin style characterizes the medium size Hole Trinity Church in Sanok. The churches in Wlodawa and Hrubieszow are the examples of the Byzantine-Russian style. The church in Tomaszow Lubelski is also a medium size as well as a St. Peter and Paul in Siemietycze, both in the Neo-Russian style. The churches in Bialystok, Hajnowka and the Resurrection Church in Siemiatycze are the largest ones.. The church in Hajnowka is well known from the International Festival *The Hajnowka's Orthodox Church Music Days* were best choirs from all over the world perform. The church of Divine Wisdom in Bialystok is interesting due to the fact that it is a miniaturized copy (1:3) of Hagia Sophia in Istanbul.

Table 1: *Acoustic parameters of church SIRs used for listening tests.*

No.	Church of the…\ Parameter	RT [s]	C_{80} [dB]	C_{50} [dB]	t_s [ms]	LEF	STI	G	Vol. [m^3]
1	Holy Trinity in **Sanok**	1,83	4,2	2,3	65	0,47	0,58	7,3	1650
2	Sacred Virgin Mary in **Włodawa**	2,09	2,6	0,8	93	0,57	0,58	6,6	2400
3	Assumption in **Hrubieszow**	1,82	4,6	2,5	59	0,21	0,61	3,3	1700
4	St. Nicholas in **Tomaszow Lubelski**	2,87	3,4	1,7	105	0,25	0,58	3,8	3050
5	St. Peter and Paul in **Siemiatycze**	2,2	0,7	-1,2	109	0,76	0,51	7,7	1500
6	Holy Spirit in **Bialystok**	6,53	0,2	-0,4	235	0,22	0,49	6,6	9500
7	Holy Trinity in **Hajniwka**	4,59	3,9	3,0	106	0,1	0,56	3,7	6050
8	Resurrection in **Siemiatycze**	4,74	3,9	3,0	106	0,14	0,56	5,8	6400
9	Divine Wisdom in Bialystok (**Hagia**)	6,14	0,9	-0,7	198	0,27	0,46	5,7	5950
10	Protection of the Mother of God in **Zdynia**	1,07	6,9	4,1	41	0,51	0,68	4,7	750
11	St. Basil in **Konieczna**	1,17	7,7	5,4	37	0,46	0,68	5,2	900

3. LISTENING SETUP

For the listening test, the 16-channel setup was prepared using the RME converters and Genelec 6010 monitors. The selected loudspeakers are quite small but their sensitive is 93 dB SPL with flat frequency response from 74 Hz to 18 kHz (±2,5 dB). The loudspeakers are spherically placed around the listener, whose configuration is shown in Fig. 1. This setup was installed at the anechoic room of AGH-UST using microphone stands with sphere diameter of 3,2 meters.

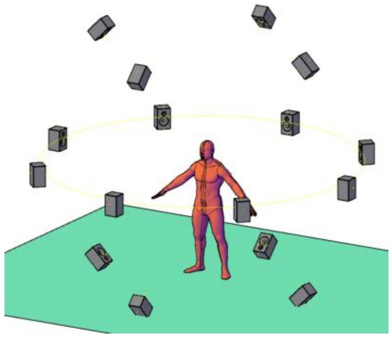

Figure 1: *The idea scheme of loudspeakers placed on sphere configuration*

The system was positioned with a laser angular meters and then calibrated and phase checked.

Figure 2: *Listening stand overview photo*

Loudspeakers of the system are situated on a sphere around a listener in three planes – above, under and on the height of listener's head. Exact angular coordination in respect to the listener are presented in the table 2.

Table 2: *Loudspeakers angular coordination in respect to the listener position*

Loudspeaker no.	φ [°]	θ [°]
1	0	0
2	45	0
3	90	0
4	135	0
5	180	0
6	-135	0
7	-90	0
8	-45	0
9	68	-45
10	158	-45
11	-113	-45
12	-23	-45
13	23	45
14	113	45
15	-158	45
16	-68	45

4. STIMULI PREPARATION

The human voice is often regarded as one of the most beautiful musical instruments. When the human voice is multiplied (like in choir), as the result of this mixture there is a sound of a very rich and interesting timber. Choral music is inseparable from Orthodox church and its tradition so as a samples in listening test, choral music exerts were used.

4.1. Raw sounds recording

In order to obtain raw audio material (without any reflections or other type of response), choral free field recording were made. Recording of chamber orthodox choir (8 singers) was performed at anechoic room of AGH-UST. The whole choir was recorded using multitrack setup using one type of microphones (Rode NT5 with cardioid capsule) for each voice. Soprano, alto, tenor and bass tracks were separately recorded and prepared for next research stages. Recorded music samples were in moderate tempo and not complex harmony, with neutral, and universal lyrics (*halleluiah*).

4.2. Raw audio samples convolution with SIRs

Finally, obtained SIRs were convoluted with a raw choir music samples. In order to place each voice in the right position of sound plan, each convolution was performed for every voice separately. As a result there were 176 convolutions (11 churches x 4 ambisonics components x 4 choir voices). After that, the B-format tracks were converted to 16-channel setup, acording to [3] and the coordinates shown on table 2.

Choir voices placement were performed using VBAP (Vector Based Amplitude Panning) technique [9]. Voices (phantom images) were placed typically for regular SATB choir accordingly to data in tables 2 and 3. Angular positions of particular voices in table 2 are the trigonometric result of typical distances between singers and 6.5 m distance from listener position. Table 3 shows calculated gain factors for specific loudspeakers of listening setup, based on VBAP.

Table 3: *Gain factors of specific loudspeakers of setup*

Voice	φ [°]	Loudspeaker no.	Gain factor
Soprano	-20	1	0,78
		8	0,63
Alto	-7	1	0,98
		8	0,19
Tenor	7	1	0,98
		2	0,19
Bas	20	1	0,78
		2	0,63

5. LISTENING TEST

The main purpose of the performed psychoacoustic procedure is to ranking measured churches in sense of *acoustic esthetics*. It is difficult to precise this kind of criteria. So, in order to find out relations between the listener preferences and the physical features of the rooms, the MDS (Multidimensional Scaling) method was employed [10]. Obtaining data about objects similarity and preferences for MDS analysis was performer using paired comparison. For 11 churches, there are 55 unique possible pairs to compare. Each test round was designed using 2IFC procedure (2 stimuli, intervaled forced-choice). After two choral music excerpts of length about 15 s each, *located* in different churches, the listener's task was to choice which of them sounds better and how much do they differ. To clarify and unify listeners task, the exact question was stated before each survey:

- *How similar are the following sound excerpts representing different interiors, where 0 denotes to totally different and 100 refers as identical?* {similarity test}
- *In which of presented auralized interiors would you prefer to listen to this kind of music? In other words: Which of the presented sounds you like more?* {preference test}

Listeners answered to these questions after each round of two sounds using tablet touch interface. Fig. 3 shows the application form window used during the tests.

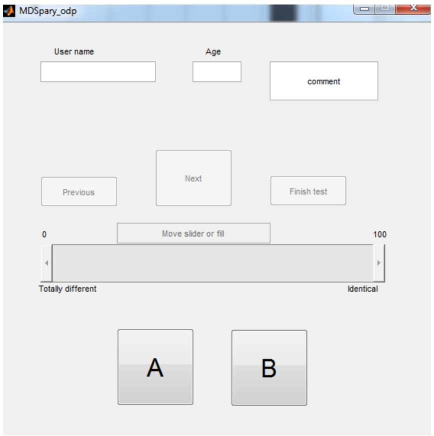

Figure 3: *Form window used during the tests*

Actual tests were followed by a few training rounds to introduce test subjects with exemplary stimuli and to practice whole test procedure. Test subjects were placed in the center of loudspeaker sphere individually to achieve similar sweet spot condition for every listener. During the tests, only the subject and the operator remained in the anechoic chamber. Whole test last for about 40 minutes so a short break in the middle of it was obligatory. Every test round was introduced by a lector, and the listeners had the opportunity to repeat every round if needed. Listening group counted of 20 people from 20 to 35 years old within 6 female. Listeners had different listening or acoustics experience and different confession. None of the listeners had impaired auditory system.

6. STATISTICAL SIGNIFICANCE OF RESULTS

Actual work discusses results of a preference test only. First step of statistical analysis is the correlation between personal listeners results. Average value of Pearson's coefficient equals 0,38 for n = 20. Zero hypothesis which assumes no correlation between answers of listeners was not rejected in 40 cases on 180 possible pairs, at 0,95 significance level. The conclusion is that alternative hypothesis assuming significant correlation of the particular results cannot be accepted. For more intuitive and visual correlation analysis, metric MDS [10] is used to visualize correlation matrix (fig. 4). It could be noticed that there are two clusters of subjects relatively close to each other. This suggests to perform analysis with respect to noticed division – separately for both groups, marked in fig. 4 as group A and B.

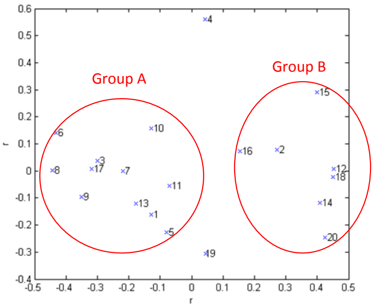

Fig 4: *Graphical interpretation of correlation matrix of results of particular subjects*

7. RESULTS

Collected data was processed in two ways. Fig. 5 shows preferences test results using Thurstone-Mosteller's least square approach [11]. Presented results are based on the probability analysis of listeners preferences in paired comparison test. Mentioned probability is calculated on the base of quantity when object *i*, was marked as preferred accordingly to other object *j*. This kind of scaling is performed for both statistically significant groups of subjects.

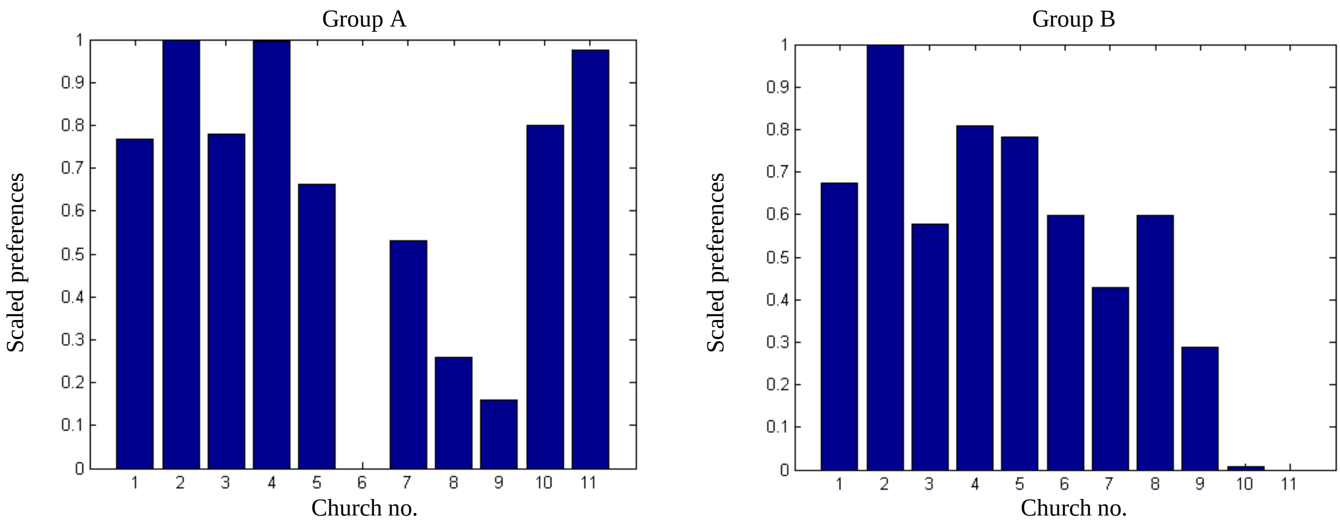

Fig 5: *Listeners preferences calculated using Thurstone-Mosteller's least square approach of data obtained in paired comparison test*

After comparison of diagrams in fig. 5 it could be noticed that the main difference between considered groups is for objects 6-11. Group A prefers objects 10 and 11 much more than objects 6, 8 and 9. Opposite tendencies can be noticed for group B. Both groups prefers objects 2 and 4 the most.
Second approach to calculation is based on non-metric MDS scaling. Difference between objects is calculated on the basis of probability of preferences according to transformation in [10]. Graphical interpretation of preferences for both statistical groups are shown in fig. 6. Applying non-metric MDS scaling within 2 dimensions resulted with stress factors of 0,11 for both groups. For random data and the same analysis parameters stress factor would equals 0,21. So according to [10], actual fitting is rated as good.

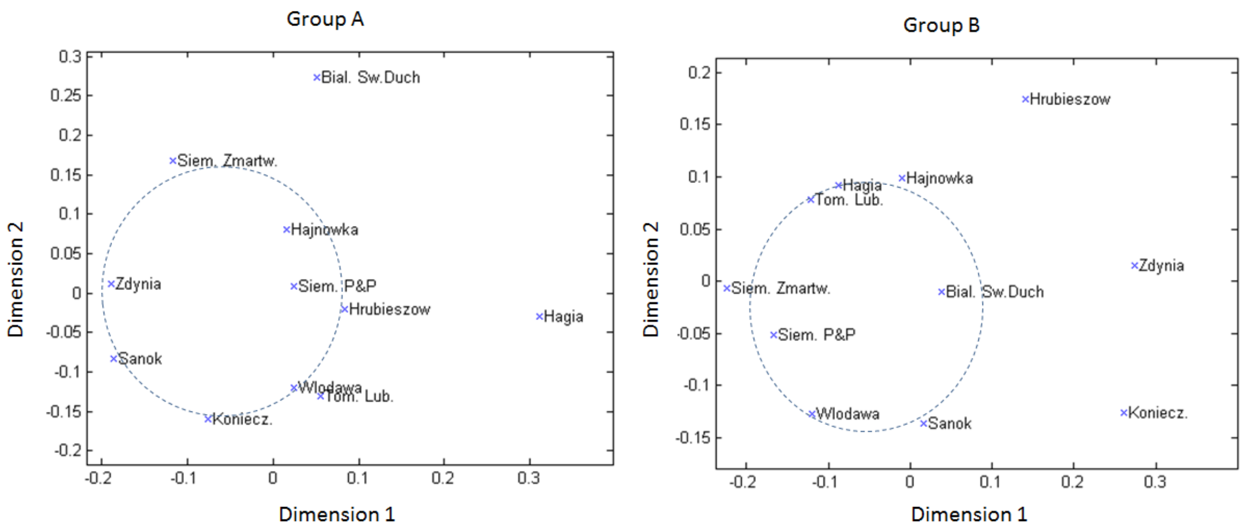

Fig 6. *Graphical interpretation of preferences for both statistical groups calculated using non-metric MDS*

For both diagrams in fig 6 there are two geometrically arranged aggregations of objects and some separated ones. For group A this separated objects are very big and reverberant and for group B very small and acoustically dead compared to others. On the basis of fig 5 and 6 it can be concluded that noticed statistical groups differs mostly in sense of negative preference. Analysis of individual subjects does not suggest any special features of any groups (age, acoustic-music experience, sex etc.) Smaller group

B contains three orthodox listeners versus one orthodox in a group A. This clue seems to be not strong enough to make some general conclusion about it.

8. CONCLUSIONS

Measurements of 11 SIRs in several orthodox churches were conducted as well as listening test using auralized samples of choral music. Tests were conducted in order to find listeners preferences about highly reverberant rooms in aspect of choral music. Auralization was performed using ambisonics and VBAP technologies. First order ambisonics was employed at every stage of research. Conducted acoustic measurements in orthodox churches in central Europe on that scale are one of the first.

Listening experiments were performed using psychoacoustic methodology and modern statistical MDS approach. Correlation analysis of results revealed two different groups of listeners. They had different preferences especially about extreme reverberant conditions. They had completely opposite opinion about very long and short reverberation time in context of choral orthodox music. Based on conducted research very interested conclusion can be stated that listeners were divided not with aspect to *what do they like*, but rather in *what do they not like*. All listeners rated medium size churches with big central dome as most preferred. Future research on current subject is planned with employment of higher order ambisonics and different approach in on place SIR measurement in order to achieve even more realistic auralization.

9. REFERENCES

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