Application of a smartphone for introductory teaching of sound environment: Validation of the precision of the devices and examples of students’ work

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Abstract: In an introductory course for environmental/architectural acoustics in universities, it is often used the teaching method based on soundscape, in which students are asked to make a sound map with listening their surrounding acoustic environment. However, if objective measurement of sound pressure level or frequency spectrum can be introduced in such a course, it will interest students in environmental acoustics, and enable them to discuss the acoustic environment more profoundly. Measurement apparatuses are usually expensive and difficult to be used in such a course. Therefore, we consider to use a smartphone: using a smartphone with acoustic measurement applications, it can be possible to introduce an objective measurement in such an introductory course for beginners. In this study, first some applications for acoustic measurement are examined to confirm their accuracy as well as the effect of a simple handmade windscreen. Secondly, using suitable applications, as a possible work in the course, sound maps with measurement results by a smartphone are made and their examples are shown. Finally, some issues to introduce this method in actual courses are discussed.

Keywords: Introductory teaching, Architectural acoustics, Environmental acoustics, Smartphone

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1. INTRODUCTION

In the university curriculum relating architecture and built environments, education on sound environment has an important role. Therefore, it is often introduced in the lower grades of university as an introductory course. Such an introductory education on sound environment has been so far carried out based on the concept of soundscape [1], and students are instructed to various sounds in different environment to make a sound map, for example. In this way, students' interest and attention are drawn to the sound environment. On the contrary, exercises using measurement apparatus such as a sound level meter to measure sounds quantitatively is useful to give a physical insight and sense of physical measures to the students. However, this kind of exercise is not generally included in the curriculum except for higher grade students or ones in a department specialized for acoustics etc. Even in such a specialized course, a trial measurement by sound level meter with some basic instructions is probably the most polite example. Therefore, it is usually difficult for students to obtain a physical insight and general sensation of acoustic quantities such as noise levels.

However, in the introductory stage of sound environment education, for example, when they are learning “what is the sound pressure level?,” it would be valuable to have an experience to measure the sounds quantitatively while listening the same sounds. In such a way, students can obtain the relationship between physical measure such as sound level and how they feel to the sounds, which can provoke their further interest and development in their studies.

In this case, preparing many expensive apparatus such as a sound level meter, which are usually not familiar to students, and ask them to find a subject of survey according to their interest, is not realistic. However, if it is possible to let the students make a survey, with their own interest, by using a less expensive and familiar instrument, it should be advantageous and effective to provoke their interest.

Considering the above situations, the authors propose the use of a smartphone (in this paper, “smartphone” is used to address all portable information devices including

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iPod touch, iPad, iPad mini, etc.). Smartphones are recently very widely spread, and many applications for acoustic measurements and analyses are provided for them: from simple measurement like sound level measurement to rather sophisticated ones like frequency spectrum, band levels, moreover, measurement of impulse response and reverberation times.

Nowadays, smartphones are quite popular among students. Therefore, using such devices, it would be possible to provide them an opportunity to make an exercise to measure physical values with their spontaneous interest [2–6]. In this report, as a test case, we conducted an introductory teaching program for understanding sound environment by using a smartphone, and discussed its potential possibility and development.

2. ACOUSTICAL MEASUREMENT BY SMARTPHONE

2.1. Application for Measuring Sound Levels

There are many applications for smartphones, for both iOS and Android, to measure sound levels. However, among them, there are some applications which cannot measure A-weighting sound levels and not usable for practical purposes. Therefore, one should be careful to choose what application is used.

In this study, we used SPL Meter (Studio Six Digital. Ver. 5.1) [7] was used for measuring sound levels. This application is available on both iOS and Android. Although it does not have integral function for measuring $L_{eq}$, it has A- and C-weighting, as well as, slow and fast time constant. Therefore, basic functions for simple sound level meter are available. This is also very inexpensive, and considered to be suitable for recommending students to purchase as teaching materials.

First, an experiment to validate the precision of the application, including the hardware (smartphone) was carried out. Calibration was made by the following procedure: Emitting 1/1-oct. band noise (center frequency 1 kHz) from a loudspeaker, we measured the C-weighted sound level of the noise by the smartphone with SPL Meter and Class 1 sound level meter (Ono Sokki, LA-4350). In this way, first the sensitivity of SPL Meter is adjusted (Detailed information of the calibration is given in Table 1). Then, A-weighted sound level of 125, 250, 500, 1k, 2k and 4k Hz 1/1-oct. noise, pink noise, white noise were measured by both the SPL Meter and Class 1 sound level meter. The measured results are compared.

As the hardware, we employed iPod touch 3 and 4, iPhone 4 and 4S, and iPad 2 as iOS device (iOS 5.0). The precisions of these devices were compared. As an example, the result for iPhone 4 is shown in Fig. 1. The measured values by iPhone 4 are on the vertical axis, and ones by the Class 1 sound level meter are on the horizontal axis. As shown in the figure, all values for 125 Hz band noise measured by iPhone 4 are lower than the ones by the Class 1 sound level meter. This tendency is observed in all iOS devices, except for iPod touch 3, which does not have a microphone and used with an external microphone. It is considered that this tendency is attributed to the characteristics of the microphone pre-amplifier included in the devices. The iPod touch 3 (with an external microphone: TASCAM iM2 [8]) does not show this tendency. However,
in all cases, except for the above tendency, the measured values by iOS devices are mostly in good agreement with Class 1 sound level meter, and can be concluded that they are almost equivalent as a Class 2 sound level meter. Regarding Android devices, Xperia SO-01C, Xperia SO-02C, GALAXY SC-02B and Medias N-04C were examined (Android OS 4.2). As an extreme example, the result for Xperia SO-01C is shown in Fig. 2. As is seen in the figure, variations of the data are more significant than iOS devices, and the tendency of higher data from a diagonal line is observed. In this device, it is considered that a limiter is installed in the microphone pre-amplifier in the device. The same tendency is observed in the case of Xperia SO-02C. As for GALAXY SC-02B and Medias N-04C, such a tendency of higher value from a diagonal line that is attributed to the limiter is not observed. Their accuracies are almost the same as those of iOS devices.

According the above results, hereafter the Android smartphones are not considered in this study.

2.2. Application for Frequency Analysis

There have been available many applications for smartphones for FFT analysis to measure frequency spectra of a sound. One example is Signal Scope Pro from Faber Acoustical [9], which provides not only FFT but also 1/1-, 1/3-octave band analyses. Also it has functions such as time integral sound level meter to measure $L_{eq}$, oscilloscope, and signal generator. However, it is rather too expensive to recommend to student to purchase.

In this study, as an inexpensive application for spectrum analyses, bs-spectrum (ver 2.1) from Bismark [10] is used. This application can prove only FFT analysis, and frequency resolution is rather low. But, it has a function to fix the display to show the instantaneous value. In the introductory education for sound environment, this application is good enough for observe the general feature of frequency characteristics of various sounds. This application has a “stop” button; therefore, one can stop measurement and taking screen shot to record the measured results as graphical data.

Here, the same iOS devices used in the experiments in the preceding section, the accuracy of bs-spectrum was examined. A pink noise is emitted from a loudspeaker in an anechoic chamber, and the frequency spectrum was measured by the devices. The results were compared by ones measured by an ordinary professional-use set-up: a Class 1 sound level meter was used as a reference microphone and pre-amplifier, and FFT analyses were done by a personal computer with the digital audio workstation software, Cool Edit Pro 2 which had the function of FFT with 2,048 points. As an example, the result measured by iPod touch 4 is shown in Fig. 3. Both results are generally in fairly good agreement, therefore, this application can be used for the present purposes. However, the results obtained by iPod touch 4 show a drop at frequencies lower than 100 Hz, and it should be noted that the results in this frequency range are quantitatively less accuracy. This problem is also attributed to the characteristics of the pre-amplifier of the microphone installed in the devices. This low frequency drop is more significant in the cases of iPhone and iPad: there is a device which show a sharp low frequency drop from about 200 Hz. On the whole, one should be careful for the measurement of low frequency sound with these devices.
2.3. Effect of a Hand-Made Windscreen

In the introductory courses it is often held a measurement exercise in outdoor. In such a case the effect of wind can affect measured results. Therefore, we tried to make a simple hand-made wind screen which fits to iPhones. The hand-made windscreen is made of plastic foam (originally used for dish washing purposes). In a block of the foam of $95 \text{ mm} \times 65 \text{ mm} \times 20 \text{ mm}$ a slit (20 mm) is made in which an iPhone is inserted (see Fig. 4). Attaching this windscreen, the measurement accuracy was examined and the results are shown in Fig. 5. There is no significant bad effect of the windscreen observed. Also, it was tested in an outdoor space with measuring the wind speed by a simple anemometer [11]. The results are shown in Fig. 6. The measurement error is less than 3 dB when the wind speed is less than 6 m/s. Therefore, this simple hand-made windscreen can be used for the educational use.

2.4. Feasibility Study for Using iPad Mini

In the University to which one of the authors belongs, all students are provided with an iPad mini when they matriculate at the university. Therefore, it should be worth discussing the feasibility of using iPad mini for the introductory course of architectural/environmental acoustics.

After having finished the course of studies on iOS devices mentioned above, a similar consideration was made for iPad mini. The devices used in the experiments is iPad mini 2 (model A1490, iOS 8.4), and the application used is SPL Meter (note that in this case Ver. 7.2 was used). The results of comparison of measured results by iPad mini and Class 1 sound level meter are shown in Fig. 7.
As is observed, the results are in good agreement. According to the information provided in the homepage of the producer of the application, the products made by Studio Six Digital for iOS 6 and above have a function to switch off the high-pass filter of the internal microphone in the device. Therefore, it is very likely that this good accuracy is attributed to the effect of this function.

3. EXAMPLES OF THE EXERCISE FOR INTRODUCTORY CLASS FOR SOUND ENVIRONMENT EDUCATION USING A SMARTPHONE

Making sound map is one of the most typical exercise assignments in the introductory sound environment education course. Practical examples are shown in this section. In the followings, three examples are shown. These exercise assignments can be done by either one student as an individual project or a group of students as a part of classwork. For example, map 1 can be done by one student alone, but map 2 will be better done by two students of whom one measures sound level and the other measures sound spectrum. However, as a trial study, all examples are made by an individual. These are made by using iPhone 4 and iPod touch 4 with SPL Meter and bs-spectrum. In the practical measurements condition, wind was calm and the results here are all measured without the windscreen.

3.1. Example of Sound Map 1: Measurement of Sound Levels

Making a sound map is generally performed in the introductory classes for environmental acoustics. However, in most classes it is difficult to prepare sound level meters for all students. Therefore, students are often asked only to listen what they hear, and arrange the results on the map based on the concept of soundscape (here this means its original idea which emphasizes the importance of listening to surrounding sound environment) [1]. Here, in order for students to obtain quantitative sense of sound level, and to understand the difference in their sensation as a difference in physical value, a trial was made to make a sound map with sound level measurement by smartphones. The test area is the south most area of Hirata-cho, Ashiya-city, which is rather quiet residential quarter, however, there are two roads with heavy traffic within 200 m distance. In this area, measurements were carried out in about ten points. The measurement device was iPod touch 4 (with installed microphone) with the software of SPL Meter. The peak value of the A-weighted sound pressure level with slow time constant was read. The sound map is shown in Fig. 8. Observation of this map will give some insight, for example: even the distance from the main traffic is the same, sound levels can differ depending on whether the observation point is hidden by a building, or whether the main traffic can be seen directly from the observation point, etc. Through such a discussion, students can gain insight into the various factors affecting the sound level and its distribution. Therefore, even though this assignment is basic, it is useful in the early stage of the introductory acoustic education.

3.2. Example of Sound Map 2: Measurement of Frequency Spectrum

As an advanced assignment, students were asked to measure the frequency spectrum as well as sound level at each point, and compare them with the feature of sound...
environment heard there. The devices used are iPod touch or iPhone (in both cases the installed microphones are used). Sound levels were measured by SPL Meter, and the frequency spectra were measured by bs-spectrum. In the spectrum measurement time window (integrating time) was set to 4 seconds. In a measurement point, the stop button is pushed when the observer judged that the most significant sound was heard so that its characteristics were caught. Then, a screen shot was taken.

An example of sound map made in this way is shown in Fig. 9. The measurement area was a typical urban area in Toyonaka-city. The sound level was rather high at the point near to main traffic, and frequency spectrum was also strongly affected by road traffic noise there. In the point near to a primary school, a line spectrum which shows a feature of human voices was observed: there was a physical education in the school’s ground when the measurement was carried out. On the other hand, in a residential area apart from main traffic and the school, the sound level was very low. This level is rather lower than that in Fig. 8, which means that there was no significant noise source relating daily life.
3.3. Example of Sound Measurement: Effect of Window on the External Noise

As a simple example of output of an assignment for students, comparing the measured sound levels in the case of open and closed window can be a useful for students to understand the sound insulation effect of window. Table 2 is a simple example of the measured results of the sound pressure levels (with A and C weighting) obtained by SPL Meter on iPad mini. Using the internal microphone of iPad mini, the external noise (mainly by rain noise) was measured when the window was opened and closed. Comparing these results, the interest on the window’s sound insulation performance can be provoked.

<table>
<thead>
<tr>
<th>Window</th>
<th>Weighting</th>
<th>Measured Level</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>A</td>
<td>53.2 dB (A)</td>
<td>When the window is closed the quite quiet in the room and the level is very low. But, when opened the level raised by more than 10 dB.</td>
</tr>
<tr>
<td>Close</td>
<td>A</td>
<td>40.4 dB (A)</td>
<td></td>
</tr>
<tr>
<td>Open</td>
<td>C</td>
<td>62.4 dB (C)</td>
<td>Even though the measurement condition is the same, and the results show a similar tendency, the difference of the level of open/close window condition becomes smaller. This is considered to indicate that either the effect of the window is low at low frequencies, or the external noise contains low frequency components mainly.</td>
</tr>
<tr>
<td>Close</td>
<td>C</td>
<td>57.4 dB (C)</td>
<td></td>
</tr>
</tbody>
</table>

4. ADDITIONAL PROBLEMS

In this report, several possible assignments were tried and the results are shown for the introductory education of sound environment by using smartphone. Mostly, positive impressions are heard from the students. Examples are as follows:

- Better understanding the relation between perceived loudness of sound and noise level.
- Also, useful to understand the relationship between impressions of sound environment and physical quantities.

The results of our trial showed the possibility of effective usage of smartphone for educational purposes.

There are, however, the issues to be solved. These are obtained by the discussions with students and listed below.

The problem of cost for software Even inexpensive (85 JPY for SPL Meter, and 350 JPY for bs-spectrum), most reliable software are not free for both iOS and Android. The opinions of the students was divided into positive and negative and the typical examples are; “acceptable: same as textbook” and “hesitated thinking about the continuous use.” Also, “The textbook may have the choice that I do not buy, but there is no option of for the software which is necessary for practical training.” The problem depends on the understanding of students.

The prevalence of the device In current situation, the students using smartphone are increasing, but all the members do not have it. It is desirable that all the students examine the problem individually based on their own interests for the assignments shown in this report. Considering the situation of insufficient distribution of smartphone, it is necessary to arrange the problems being examined in a group. Additional problems also arise such as a feeling of unfairness of students bearing cost. Further cost problem would arise if the advanced measurement are assumed such as band level analyses or $L_{eq}$. Possible solution is preparing and offering the sufficient number of devices such as iPod touch with necessary software installed for each group.

5. CONCLUDING REMARKS

The examples of trials of using smartphones, which were used as the acoustic measurement apparatus with appropriate software, in the introductory education program of environmental acoustics were described. In addition to the representative smartphones of iPhone, Android, the mobile devices such as iPod, iPad, were also used. The potential accuracy and performance of typical inexpensive measurement software were examined. Also, examples in the practical assignment of making sound maps were shown. Results showed that iOS products showed sufficient performance in the measurement of noise level. Some of the Android device showed equivalent performance as iOS device, but not the all. As well known, too many devices exist for Android type. The effective suggestions for the sound limiter in devices, or some kinds of authorization system would be valuable topics. Needles to say, these regularization and discussions for linearity are not limited for acoustical applications, but also available for illumination photometer applications, for example. More and more spread is expected for the smartphone. However, the careful consideration would be necessary for educational use unless 100% distribution is assured. The availability of smartphone as elementary measurement apparatus are shown in this report. Advanced assignments and practical introduction in the university curriculum are examples of our current subject.
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