Acoustics and the smartphone

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ABSTRACT

With the rapid increase in the use of smartphones such as the Apple iPhone™ and Android™-based phones, a range of low cost acoustic tools are now available to acoustic professionals and the general public. This paper explores some of the software tools currently available for smartphone devices, evaluates their measurement accuracy and discusses their potential place in the acoustic professionals testing and analysis kit. The results of several experiments comparing the results from 'traditional' sound level meters and smartphones are presented. Tested scenarios include sound pressure measurements from various sources and room acoustic measurements. A review of the shortfalls of the smartphone based tools currently available is also undertaken. The results of the study show that these new devices can provide useful results under some measurement conditions. However there is as yet no substitute for a sound level meter designed and calibrated in accordance with the relevant international standards.

INTRODUCTION

Many noise measurements undertaken by acoustic professionals are required to be undertaken in accordance with specific international standards (International Electrotechnical Commission 2003). However it is noted that there exists a significant component of noise measurements undertaken by the professional that are not required to comply with a specific standard or requirement, e.g. a measurement used to check a design or to provide guidance as to the frequency content of a tonal source etc.

With the rapid increase in the use of smartphones such as the Apple iPhone™ and Google Android™, a range of low cost acoustical tools are now available to acoustic professionals and the general public. Tools available include a range of measurement and analysis tools through software applications ('apps') and hardware attachments which cover such tasks as advanced frequency analysis and building acoustics measurement and analysis. As such, these new tools can significantly reduce manual processing and potentially replace expensive equipment at a fraction of the cost.

For the purpose of this paper, the investigation into the accuracy of these devices is limited to the comparison of measurements of overall and one-third octave band noise levels, and the measurement of reverberation time. This allowed a comparison of results for a smartphone without additional peripherals, e.g. an external microphone or a loudspeaker. The model of smartphone used for these experiments was the Apple iPhone™ 3GS (iPhone™), due to the extensive software and support available for this device.

ACOUSTIC TOOLS FOR THE SMARTPHONE

A search of the iPhone™ App Store, Android Market and online sources show that there are various applications available for acoustic measurements, including:

- Basic sound level meters
- Sound recording
- Frequency analysis applications, including octave band and FFT measurements
- Signal generators, including pink noise and sine sweeps
- Room acoustic measurement applications
- Basic room models for calculating reverberation time using sabine equations and a built in data library
- Time history logging of sound levels
- Sound system distortion, impedance and delay
- Basic acoustic calculations and noise level manipulation
- Cross-talk cancellation for presentation of binaural recordings over loudspeakers

LIMITATIONS OF THE SMARTPHONES

Acoustic Measurement Standards

Many noise measurements undertaken by acoustic professionals are taken in accordance with specific standards and guidelines. For these measurements, laboratory calibrated sound level meters are required. Multiple International Electrotechnical Commission (IEC) standards define the requirements for sound level meters to comply with a relevant class of accuracy.

The basic functionality of the iPhone™ applications used for this paper fulfil a majority of the general requirements for sound level meters described in Section 5 of IEC 61617-1. There are however requirements of this standard that the smartphone used for these experiements does not comply with, notably key accuracy requirements such as the maximum allowable electroacoustical tolerances and performance under varying environmental conditions. Potentially these limitations could be overcome by the addition of a Class 0 compliant microphone and preamp in combination with the smartphone as part of the measurement chain. The authors acknowledge that it is very unlikely that a smartphone (or smartphone based measurement system) will comply with such strict standards and requirements without the hardware of the smartphone being modified to meet the specific requirements of a sound level meter.

Limitations of hardware and software

The internal microphone of the Apple iPhone™ 3GS was found to have a low frequency filter (below 200Hz) applied to the microphone (Faber Acoustical LLC n.d.). This is consistent with primary use of the microphone for recording and transmitting speech, where the frequency range between 350Hz – 4800Hz is most important (American National Standards Institute, Inc. 1997). Caution is required therefore in the use of these tools to measure noises with significant low frequency components.

Furthermore, early models of the iPhone™ had an internal microphone sample rate of 8000Hz, limiting the upper range of measurement. Later models have an increased sample rate of 48000Hz, allowing for a broader frequency range for measurements (Studio Six Digial n.d.).

The measured frequency response of the internal microphones of several iPhone™ models is shown below in Figure 1. At the time of this paper data was not available for the iPhone™ 4.

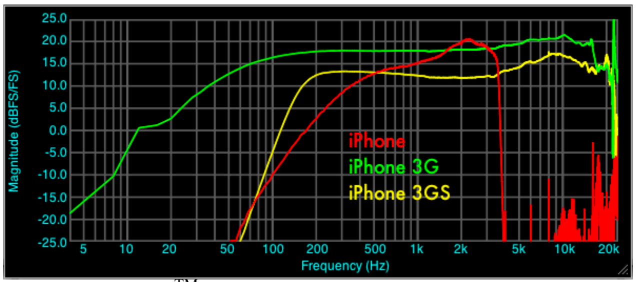

Figure 1. iPhone™ internal microphone frequency response (Faber Acoustical LLC n.d.)

EXPERIMENTATION

Methodology

Experiments were conducted to compare the iPhone™ results to a traditional sound level meter for sound pressure level and reverberation time measurements. These measurement types were selected to represent the types of spontaneous measurements that are occasionally required where an acoustic professional may only have a mobile phone at their disposal.

A Brüel and Kjær 2250 (B&K) was used for the purposes of comparison for both sound pressure level and reverberation time measurements. This data was compared to the results from two applications for the iPhone™ that can record 1/3rd octave noise levels and can receive an external impulse. From this impulse the user can select the decay and calculate the reverberation time. The experiments were setup to mimic typical field use of a hand held sound level meter. Both the iPhone™ applications and the B&K were set to the same common measurement settings where possible, e.g. A-weighted, fast response etc. The B&K was in laboratory calibration at the time of the measurements and was field calibrated to 94 dB(A) +/- 0.5 dB using a reference test tone.

All measurements comparing the B&K and iPhone™ results were done simultaneously, with the two devices directly adjacent to each other.

Sound Pressure Level Measurements – Results

The SignalScope Pro by Faber Acoustical, LLC (SSP) application was used on the iPhone™ for the measurement of sound pressure levels. A variety of noise sources commonly encountered by an acoustic professional were chosen to compare the measurement results of the iPhone™ and B&K. These sources included road traffic noise near a busy street, compressor noise and background noise levels in a commercial office boardroom. The noise sources varied in loudness, frequency content and time variance (steady state or transient). A comparison of the overall (A-weighted and linear) results from both devices is shown in Table 1.

Table 1. Comparison between B&K and iPhone™ results

Noise source	*Leq, various time periods*			
	B&K		*iPhone™ (SSP)*	
	dB (lin)	*dB(A)*	*dB (lin)*	*dB(A)*
Compressor	55.1	54.2	58.7	54.6
Quiet office – services noise	50.8	49.6	51	45.8
Boardroom (145 m^3) – road traffic and services noise	40.5	38.8	45.1	39.4
Road traffic noise (including horn and engine braking noise)	74.9	75	74.2	72.2
Car horn (~3 metres)	86.5	87.5	83.3	84

A review of the results found that the iPhone™ and the B&K results were typically within 5 dB of each other. The iPhone™ also tended underestimate the dB(A) level and overestimate the dB(lin) level compared to the B&K. However, the results showed reasonable levels of agreement for a high level assessment.

Additional measurements were undertaken in a room with a loudspeaker generating pink noise at various noise levels to further explore the accuracy and limitations of the iPhone™. The iPhone™ and B&K were placed within the direct field and simultaneous measurements were undertaken. Furthermore, for this experiment two iPhone™ applications, Real Time Analyzer, as part of the AudioTools package by Studio Six Digital (RTA) in addition to the SSP application was used to explore the accuracy of sound pressure level measurements.

Figure2, Figure 3 and Figure 4 below present the measured L_{eq} noise levels in one-third octave bands for the background noise level and two levels of pink noise, as measured by the B&K.

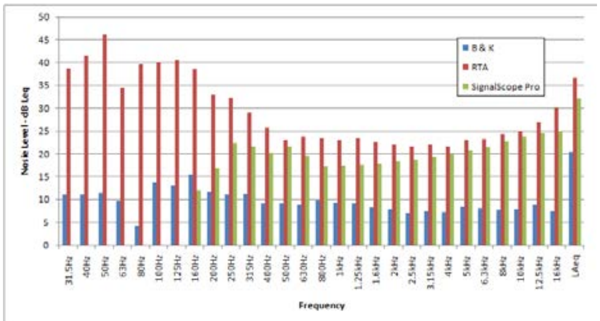

Figure 2. Comparison between B&K and iPhone™ apps

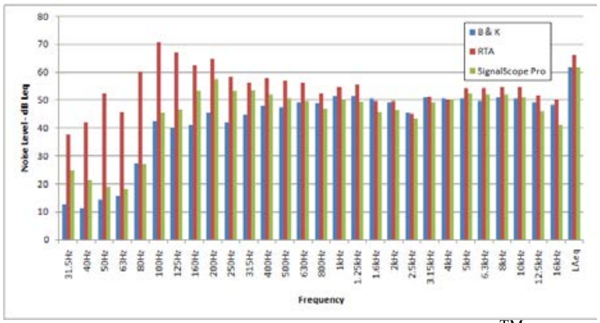

Figure 3. Comparison between B&K and iPhone™ apps

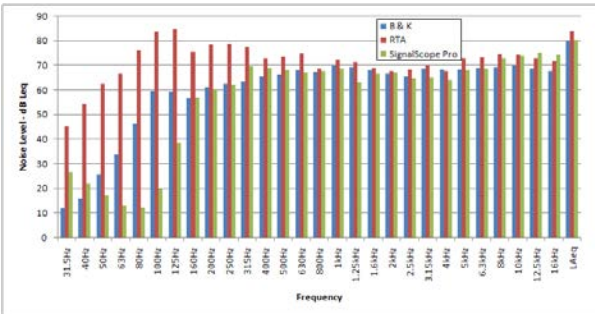

Figure 4. Comparison between B&K and iPhone™ apps

Sound Pressure Level Measurements - Analysis

It was evident during low noise conditions that the noise floor of the iPhone™ and internal microphone influenced the measurement results. A noise floor of approximately 32 dB(A) was evident. Figure 2 shows the noise floor in 1/3rd octave bands for both of the iPhone™ applications.

The documentation of both manufacturers of the iPhone™ applications used for this experiment note the poor low frequency response of the internal iPhone™ microphone. However one point of difference is that no 'correction' or 'calibration factor' is applied by the SSP application, whereas the microphone output has been 'compensated' by the RTA application (Studio Six Digial n.d.). All three sets of measurements from the SSP application show a large roll off from 200Hz and below whereas the RTA application greatly overestimates the low frequency noise component in all measurements. As these measurements were taken on the same iPhone™ sequentially in the same room and with a constant level pink noise source, this is postulated to be a function of the compensation applied by the application.

Furthermore, comparison of the measured one-third octave bands between 500Hz and 1.25kHz inclusive showed that the RTA application consistently gave higher noise level readings (between 2 – 5 dB) than the SSP application. This trend was most evident from the very low level measurement (~20 dB(A)) and may also be as a result of the compensation applied. For these bands, the SSP application gave results comparable to the B&K results, typically within 1 – 4 dB. Therefore the SSP app appears to be the better of the two apps reviewed for sound pressure level measurements.

The experiments also indicated that the iPhone™ is limited by a lower noise ceiling and therefore has a smaller dynamic range than typical professional sound level meters. Figure 5 shows the difference between measurements undertaken using the RTA application and the B&K for a loudspeaker generating a source level of approximately 100 dB(A).

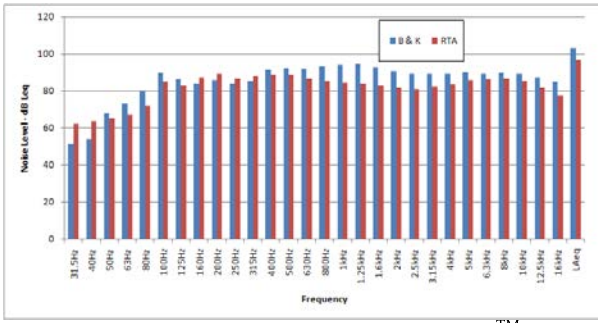

Figure 5. Comparison between B&K and iPhone™ noise ceiling

It is therefore concluded that the performance of the iPhone™ has limitations in terms of a high noise floor, low noise ceiling and reduced frequency range. Caution should be applied to measurements of noise levels below 40 dB(A), above 80 dB(A), or with significant frequency content below 200Hz.

Reverberation Time Measurements – Results

For the reverberation time measurements, the Impulse Response module of the AudioTools package by Studio Six Digital was used on the iPhone™. The same B&K meter as used for the sound pressure level measurements was also used to measure reverberation time. An impulse sound was generated using a loud hand clap and the slamming of a thick book (Bies and Hansen 2003) on an available surface to replicate the type of measurement that may be taken spontaneously in the field. Both the iPhone™ application and the B&K were set to the same common measurement settings where possible, e.g. use the T30 to calculate reverberation time. T20 results were not available from the iPhone app. A summary of the measured results is displayed in Table 2 and Table 3. The results have been presented as 'Low' and 'Mid' reverberation bands as defined in AS/NZS 2460 (Standards Australia/Standards New Zealand 2002). The 'High' band is an average of the measured reverberation times between 1.6kHz and 3.15kHz inclusive. The measurement results are an average of multiple speaker positions in each room.

Table 2. B&K measured reverberation times

Location	*Room Volume (m^3)*	*Method of excitation*	*Reverberation time (s)*		
			Low	*Mid*	*High*
Small Meeting Room	29	Loud Clap	0.4	0.4	0.5
		Book slam	0.5	0.4	0.5
Board-room	145	Loud Clap	0.9	0.7	0.8
		Loud Clap	N/A	0.7	0.8
		Book slam	0.6	0.7	0.7
		Book slam	0.7	0.6	0.7

Table 3. iPhone™ measured reverberation times

Location	*Room Volume (m^3)*	*Method of excitation*	*Reverberation time (s)*		
			Low	*Mid*	*High*
Small Meeting Room	29	Loud Clap	0.6	0.5	0.6
		Book slam	0.7	0.5	0.6

Location	*Room Volume (m^3)*	*Method of excitation*	*Reverberation time (s)*		
			Low	*Mid*	*High*
Boardroom	145	Loud Clap	0.8	0.8	0.9
		Loud Clap	N/A	0.8	0.9
		Book slam	0.8	0.9	0.8
		Book slam	0.8	0.8	0.8

The measurements were then repeated using a loudspeaker and the interrupted pink noise method for reverberation time estimation in order to determine the performance across a larger range of frequency bands and to avoid the physical limitations of human generated impulses. The results are presented in Table 4 and Table 5.

Table 4. B&K measured reverberation times

Location	*Room Volume (m^3)*	*Method of excitation*	*Reverberation time (s)*		
			Low	*Mid*	*High*
Small Meeting Room	29	Interrupted pink noise	0.5	0.4	0.6
Boardroom	145	Interrupted pink noise	0.7	0.7	0.8
		Interrupted pink noise	0.7	0.7	0.8

Table 5. iPhone™ measured reverberation times

Location	*Room Volume (m^3)*	*Method of excitation*	*Reverberation time (s)*		
			Low	*Mid*	*High*
Small Meeting Room	29	Interrupted pink noise	0.7	0.5	0.6
Boardroom	145	Interrupted pink noise	0.8	0.8	0.9
		Interrupted pink noise	0.8	0.8	0.8

The results have been further split into one-third octave frequency bands, shown in Figure 6, Figure 7 and Figure 8.

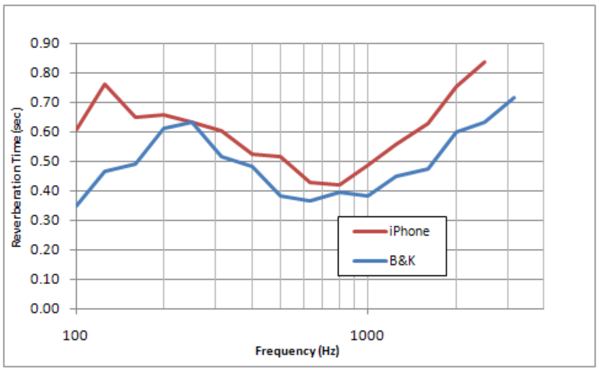

Figure 6. Small Meeting Room (Interrupted pink noise)

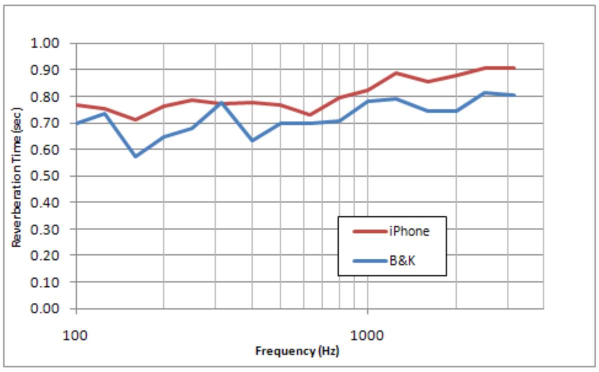

Figure 7. Boardroom – Position 1 (Interrupted pink noise)

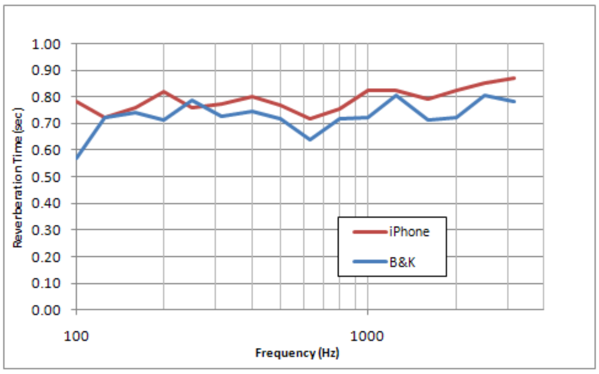

Figure 8. Boardroom – Position 2 (Interrupted pink noise)

Reverberation Time Measurement – Anaylsis

The results obtained from the B&K and the iPhone™ were within +/-0.2 seconds of each other with the iPhone™ tending to calculate higher reverberation times than the B&K. These results were consistent for both the impulse and the pink noise method. Greater discrepancies are evident at lower frequencies. These low frequency differences can be attributed to insufficient energy at these frequencies to excite low frequencies in the test rooms. As such, this is a function of the excitation method used, rather than a reflection on either the B&K or iPhone™ as a measurement tool provided the user understands the limitation of human generated impulses and the average over-estimation by the iPhone™ application.

The calculation of reverberation times did not seem to be as affected by the frequency response of the iPhone™'s internal microphone as sound pressure level measurements, and produced reasonably comparable and replicable reverberation time results. As such, the iPhone™ could be a useful tool for quick estimations of reverberation time in the field.

The method of calculating reverberation time using the iPhone™ application should be noted. The user views a trace of decay and then zooms to select the desired section of the decay. This is then saved and the application calculates the desired room acoustic parameters, including reverberation time. This introduces a level of uncertainty into the calculation as it is not known how the application uses this data range to calculate the T30. The B&K calculations are based on an international standard for the calculation of reverberation time (International Organization for Standardization 2003).

STUDY LIMITATIONS AND FURTHER POSSIBILITIES

This paper has focused on the usefulness of a smartphone as a stand alone tool. Add-on devices exist which may extend the scope of the smartphone. For instance, it is noted that the 'headset' microphone which is shipped as standard with iPhone™s has a notably flatter frequency response at low frequencies and is likely to increase the frequency range of the iPhone™. It is also understood that a measurement device connected via the iPhone™ 'dock connector' is not passed through the voice filter. Manufacturers have developed measurement microphones and line input devices using this connector, and available data indicates that these have a very flat response even at low frequencies.

Tablet devices such as the Apple iPad and Samsung Galaxy Tab also exist with increased processing power and screen size. These devices can do everything the smartphones can do, but have additional benefits in terms of data storage and processing power.

An analysis of the possible room acoustics processing versus more expensive instrumentation and software is one possibility for future study. The Studio Six AudioTools application used in this paper to calculate reverberation time can also calculate Clarity (C50, C80), Early Decay Time, Definition, and can import impulse responses recorded using other equipment for analysis.

Applications are also available for the measurement of vibration using the iPhone™'s built in accelerometer; however the sample rate of the accelerometer is 100Hz which limits the range of measurement in the application (Faber Acoustical LLC n.d.). Such applications have not been tested or reviewed by the authors at this time, but could form the basis of further study.

As discussed earlier, the investigation into the accuracy of these devices has been limited to the comparison of measurements of overall and one-third octave band noise levels, and the measurement of reverberation time. An investigation into effects such as grazing incidence was not undertaken. Full laboratory testing in accordance with the *AS IEC 61672.1-2004* and *AS IEC 61672.2-2004* could also be considered to provide a more complete picture of the performance of the devices. This assessment has also focused on the iPhone™ 3GS, additional study would be required to establish if the results of this study is applicalbe to the full suite of available smartphone technology.

CONCLUSION

This paper has explored some of the software tools currently available for smartphone devices and discussed their limitations. It was found that the internal microphone of one common smartphone has a limited frequency range and limited dynamic range, which limits the conditions under which sound pressure level measurements can be undertaken. In particular, caution is required in the measurement of noise levels below 40 dB(A), above 80 dB(A) or with significant low-frequency noise components. Nonetheless if the user is aware of these limitations and understands the type of the noise source that they wish to measure, some useful results can be obtained.

For reverberation time measurements, it was found that the smartphone used provided comparable and repeatable results to a professional sound level meter in most circumstances. The reverberation time calculations relied on relative noise differences and as such appeared to be less affected by the low frequency limitations and dynamic range than sound level measurements.

The iPhone™ applications do not comply with relevant international standards and cannot be used in place of a professional sound level meter for formal noise measurements. However they can provide a useful supplement to these tools for quick measurements in the field when the user understands the limitations of the devices.

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