Using iOS Devices for Noise and Vibration Measurements

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iOS devices, namely Apple iPhones and iPads, are being used increasingly for professional and scientific applications. Using an iOS device for noise and vibration measurements is an application with many advantages, given its small size, availability, cost, and ease of operation. A system for measuring noise level, logging noise over time, doing FFT frequency analysis of sound, and measuring speech intelligibility has been created. This platform has been developed to use either an iPhone or iPad as a host device. This provides a portable, cost-effective and easy way to deploy a test and measurement system. This article demonstrates the operation of the system, discusses the accuracy and limitations of the hardware devices, and shows how it is possible to obtain either casual or reference-quality measurements using mobile devices.

As iOS devices become more powerful, they are often being considered for applications outside their initial intended use. For example Kardous and Shaw recently investigated using a number of smartphone applications for sound measurement, specifically investigating the accuracy of such apps for noise measurements.[1] Their findings suggest that smartphones have the ability to be used for occupational noise measures as long as the user knows the limitations of the accuracy of the software being used, which was found to be variable with respect to a reference sound level meter.

While this study limited the scope to applications that measure sound pressure level, smartphone apps can be extended to analyze a complete set of noise and vibration measurements. This is afforded by the fact that the development of custom smartphone software, specifically on the iOS platform, is within reach of many software developers.

One specific extension of this application area is to use iOS hardware coupled with custom software to develop a solution for acoustical analysis and making noise and vibration measurements. Here we examine the challenges and potential solutions for using iOS devices for such cases.

Why Use an iPhone or iPad?

The choice to use iOS devices as the platform for test and measurement solutions was due to the clear advantage over other purpose-built audio and sound meters using dedicated hardware for the developer.

The first advantage over dedicated hardware solutions is that iOS devices enjoy tremendous economies of scale. Take, for example, the development of the iPhone. In seven years, users have seen nine iterations of the hardware device, each providing substantial improvements in terms of speed, usability, storage capacity and processing power while largely remaining at the same retail price for the consumer. Dedicated hardware devices are not afforded the same economies of scale.

In addition to the hardware, Apple provides a unique infrastructure to support access to and updates of software in a way that is much more convenient than flashing firmware to a dedicated hardware device, or relying on legacy connections (such as RS-232) to move software updates from a PC to a dedicated hardware device. Because many of the iOS devices are "always on line" through wireless LAN or cellular connections, as soon as an update to software is available, it may be automatically updated on the user's device. This workflow makes keeping software up to date very practical while saving time and effort for the end user.

Hardware Considerations. For development of a custom application for acoustical test and measurement, Apple provides a uniquely advantageous ecosystem for successful development and deployment of custom software. Apple provides all of the hardware R&D and creates a unique ecosystem for developers to create and disseminate software to users.

Processors. iOS devices employ near-desktop-level CPU, GPU, floating-point coprocessor, RAM and storage. At the time of this writing, the current state of the art iPhone, for example, has up to 128 GB of fast, solid-state storage, a 64-bit A8 hardware chip with M8 motion coprocessor and 2 GB application RAM. Even the first iPhone included a floating-point co-processor, which provided insight into Apple's intentions to make the iPhone (as well as the yet-to-be-released iPad and iPad touch) a technical platform capable of supporting advanced applications such as test and measurement.

Communications. Using an iPhone for measurements affords the user a number of options for extracting data from the device and delivering it to the home base from a remote test site. If a Wi-Fi network is available, data can be transmitted at the end of a test or in real time if event notifications are required. If no Wi-Fi network is available, the cellular data network can be used. And if neither is available, the data can be stored on the local device and uploaded when network connectivity becomes available.

A cloud-based storage solution (such as Dropbox) is one service that may be used that directly supports real-time file transfer and automatic caching and file syncing as network availability allows. These services are an excellent example of the synergy that developing for a mature ecosystem such as iOS affords.

Dropbox is essentially "plug-and-play" for an iOS app developer. By utilizing the protocol within a platform, the developer immediately has access to a rich cloud-based storage and file transfer system that is ubiquitous in the PC market today. These services are fast, secure, and cross platform. If the user has a laptop and multiple iOS devices, using this service for a storage strategy facilities both file transfer and backup. The time and effort that it would take to independently develop such a cloud-based storage protocol on a dedicated hardware device would be largely out of reach for many developers. Using techniques such as this lets a developer focus on algorithm and UI design for test and measurement software and not on ancillary technology for storage, sharing, email etc.

Transducers. A number of transducer choices are available for iOS devices. Next, the accuracy and limitations of the internal transducers are discussed as well as the availability and range of external transducers that are available.

Built-In and Other Analog Transducers

Built-in iOS Device Microphone. This transducer is available to all iOS devices and is the most cost-effective option for sound level testing. It also makes for the most compact measurement solution, since no additional hardware is required for end users to attach to their iOS devices. But it is not without compromise and has implications in terms of its accuracy and suitability for audio testing.

Within-device agreement for a given model of an iOS device has been consistent; highly correlated and repeated measurement results can be seen with response to both mic sensitivity and frequency response. However, across models, the frequency response is variable not flat.

In particular, the low-frequency roll-off varies quite a bit from device to device and also has been subject to change when Apple releases a new version of the operating system.

Starting with iOS 6, Apple made available test and measurement more for the analog input. Test and measurement mode disables the auto-gain (compressors and limiters designed for optimizing speech) and removes most of the high-pass filtering, which again is designed for removing window noise and pops from speech to

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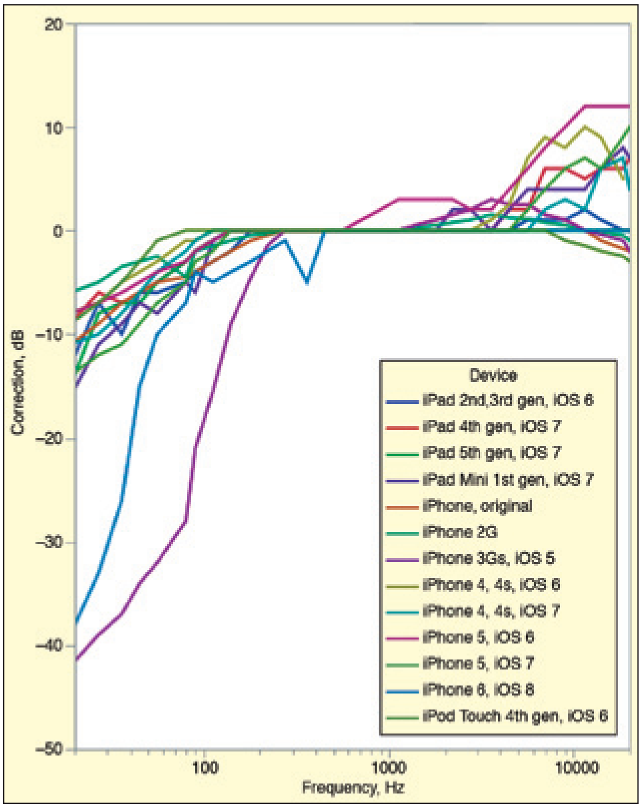

Figure 1. Correction curves for historical iOS devices employed in a measurement platform.

improve cell phone communications. This is an improvement over previous modes, but when this mode is activated, varying input response can be seen.

Figure 1 illustrates some of the microphone compensation curves that can be developed to flatten typical iOS-device-built mic response. Platform developers are able to programmatically determine which device their software is being run on and adjust a frequency response function accordingly by storing all of the potential functions in a database within an app and choosing the correct one based on the information that the OS is reporting at run time. This is one example of the reporting facility that Apple provides. After the device and platform are determined, it is trivial to apply the appropriate correction curve to the analysis.

Third-Party, Headset-Connected Microphones. Several companies are building small microphones that plug into the headset jack of the iOS device. Some advantages to this approach are that the microphone is moved a few inches from the iOS device, and the microphone often includes a calibration correction curve that may be imported into the iOS app (if that feature is supported). Drawbacks to this approach include the fact that the analog input electronics of the iOS devices vary in sensitivity and in frequency response in a similar manner to the built-in microphone, as discussed above.

Another drawback is the fact that there is crosstalk between the output and input electronics of the headset jack, so if an output test signal is used with a headset microphone, some of the output signal will bleed back into the input. This is not the same as side tone, but rather an artifact due to the grounding scheme and analog electronics. Both the microphone and output share the same ground. Table 1 reports some of the bleed values measured at the headset mic input from a signal at the headset jack output.

Table 1. Crosstalk levels measured in a number of iOS devices.

Device	Crosstalk, dB
iPod Touch	–50
iPhone 4s	–10
iPhone 5	–20
iPhone 5s	–10
iPad 3	–50
iPad 4	–50
iPad Air	–10

Other Transducers. A number of additional transducers are available to developers to access and use in their applications. This includes such sensors as a gyroscope, moisture sensor, compass, ambient light sensor, motion sensor/accelerometer and proximity sensor. This shows the rich interface available when developing for iOS.

External, Digital, Audio-Connected Transducers. Starting with Version 7.0, iOS supports USB audio input through the Lightning or 30-pin connector for all devices through the Apple Camera Connection KitStarting and has supported digital audio through the connector since iPhone 4. So, 48-k, 24-bit digital audio may be input into the iOS device completely bypassing all Apple analog electronics and transducers. In this case, the device is simply a mobile computer, which is the host processor, user input device, and display. There are several types of devices that may be used for input.

Generic USB Audio Input Devices. These include generic USB audio devices such as the Sound Devices USB Pre. Users would supply their own microphone for audio and calibrate the microphone sensitivity in the iOS app. Challenges for this method include providing power to the USB device, since the Apple iOS device will not supply more than a few mA of power, and maintaining calibration, since the input level controls are continuous and may not be locked. In general, external devices, that are bus powered do not require any extra drives and USB 1 will work. In some cases, though, features such as duplex recording or microphone power are not fully supported. In other cases, there may be interruptions to the audio stream causing clicks and pops or lost information during playback or recording. This is suboptimal for measurement applications.

Generic iOS Audio Accessories. Similar to the USB input devices, these provide a digital audio input path and normally are powered with external power adapters. Several will run on iOS power, but these do not supply phantom power for a microphone.

Test and Measurement iOS Accessories. These devices are built specifically for test and measurement and have the advantages of digital audio input, fixed and repeatable calibration, and either internal battery power or they are powered from the iOS device so that they may be used in the field away from AC power. These include:

i*AudioInterface2* – This is designed to work with any phantom-powered microphone and may be used with a Type 1 compatible microphone. It also provides a second line input and a line output. This device may also be used as an audio input device for other transducers, such as the output ICP-powered preamps so that existing sensors may be used with the iOS apps. This device supports a wide range of input and output levels to accommodate different devices.

iTestMic – This is a Type 2-class microphone that plugs in directly and transmits its sensitivity calibration to the iOS device so that readings are referenced to a calibrated SPL level.

iPrecisionMic – This is a Type 1-class microphone that plugs in directly and also transmits its sensitivity to the app. It uses a screw-on capsule and may be calibrated with a standard SPL calibrator such as a Brüel & Kjær 4231.

User Conveniences

iOS devices are simple to use, inexpensive, easily upgradable, and ubiquitous. In most cases, iOS devices are less expensive than dedicated hardware. Dedicated hardware also has the disadvantage of obsolescence, infrequent software updates and shortcomings such as monochrome LCD screens, which make it difficult to see data and results clearly.

Another benefit of using an iOS device is the availability of replacement hardware and accessories. If an engineer damages a device during a job, in most cases, no matter where he or she is in the world, a replacement device can be found in short order. And again, because Apple provides a unique infrastructure for software license management, all a user would need to do is to type in their Apple ID, and in a few minutes their entire configuration, including software, is downloaded to the device.

The same is true for accessories such as charging/sync cables, power supplies, etc. All of these can be easily sourced locally and inexpensively. This is a big advantage of using an iOS device for test and measurement as opposed to a dedicated hardware that, if damaged, would require a costly trip to the manufacturer to be repaired. In most cases, if damage occurs to a device when an engineer was to perform a job, this would be a problem that would jeopardize his/her ability to complete the work.

As noted previously, Apple is constantly innovating and releasing new versions of its hardware with larger screens, more features, higher-resolution displays, more RAM, more storage and are releasing them largely at a similar price to the last version of the hardware.

Sample Applications

Pro Test & Measurement Apps. The iTunes App Store contains many "decibel meters" and analyzers that are of dubious quality. However, there are several options available for professional quality sound level testing and analysis. Kardous and Shaw[1] evaluated the accuracy of numerous smartphone sound measurement applications and found that several were accurate within ±2 dB from a reference sound level meter. Their conclusion suggests that the iOS platform is capable of critical noise measurement given the right choice of software.

Studio Six Digital AudioTools. AudioTools includes modules for SPL logging to 1/3-octave, L_n statistical analysis, recording of sound events above a trigger level, FFT analysis to 1/48th octave and RTA octave and 1/3-octave analysis, and more. AudioTools algorithms are designed to meet all Class 1 ANSI and IEC standards, and when used with suitable hardware, the entire instrument may be certified as a Type 1 instrument by a calibration lab. AudioTools also includes options for STIPA speech intelligibility, LARSA loudspeaker and room system analysis, spectrographs, transfer function, impulse response, and others.

Faber iO Scope. Faber Acoustical provides a number of high-quality analysis apps, including iO Scope and others.

Challenge of Interruptions

A disadvantage of using a cellular phone as a measurement device is that the engineer can easily be distracted or interrupted by a phone call, email, text message or other system message. Fortunately, the system provides provisions for minimizing these interruptions and for critical applications, which require an extended period of measurement time without interruptions. Modes such as "airplane mode" can be turned on to isolate the iOS device from the outside world. Also, notifications can be turned off so that interruptions can be eliminated, and the phone may be forwarded to another number to prevent an unintended call coming in.

Real-World Application

One case for using an iPhone-based system for test and measurements comes from Greg Goetchius, who is a senior technical specialist, NVH at Atieva (formally senior technical specialist, Tesla Motors). An iPhone and measurement software (AudioTools) was used as the primary diagnostic tool, which was used to gather noise data and to determine the source of a sound. This software and hardware were also used to analyze frequency and relative dB level of noise being measured.

The acoustical analysis techniques involved using an application for real-time, fast Fourier transform and real-time analysis. This was used to take a snapshot of an offending noise, often during a test drive. One additional challenge was that these vehicle test drives often occurred away from the main test laboratory or manufacturing facility. The primary goal was to get an accurate snapshot of the noise and also have an affordable and readily available measurement system. The technician read the frequency spectral components and relative dB levels directly from the iPhone screen. These factors would often indicate a likely source of the noise, so that counter-measures could be taken.

Reference

1. Kardous, C. A., and Shaw, P. B., "Evaluation of Smartphone Sound Measurement Applications," *Journal of the Acoustical Society of America*, Vol. 135, No. 4, EL186-192, 2013.

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