

A practical tablet-based hearing aid configuration as an exemplar project for students of instrumentation

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Abstract

This paper presents the configuration and digital signal processing details of a tablet-based hearing aid transmitting wirelessly to standard earphones, whereby the tablet performs full sound processing rather than solely providing a means of setting adjustment by streaming to conventional digital hearing aids. The presented device confirms the recognized advantages of this tablet-based approach (*e.g.*, in relation to cost, frequency domain processing, amplification range, versatility of functionality, component battery rechargeability), and flags the future wider-spread availability of such hearing solutions within mainstream healthcare. The use of a relatively high sampling frequency was found to be beneficial for device performance, while the use of optional off-the-shelf add-on components (*e.g.*, data acquisition device, high fidelity microphone, compact wireless transmitter/receiver, wired headphones) are also discussed in relation to performance optimization. The easy-to-follow configuration utilized is well suited to student learning/research instrumentation projects within the health and biomedical sciences. In this latter regard, the presented device was pedagogically integrated into a flipped classroom approach for the teaching of bioinstrumentation within an Allied Health Sciences School, with the subsequent establishment of positive student engagement outcomes.

Introduction

The primary aims of this paper are two-fold. Namely: i) to provide an

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easy-to-follow, practical tablet-based hearing aid configuration exemplar of potential interest to students and educators of computer interfacing and digital signal processing (DSP) within the areas of health and biomedical engineering; and ii) to describe the pedagogical approach, along with student learning and engagement outcomes, associated with the implemented of i) within the teachings of a health-faculty-based Bioinstrumentation course. A precursory declaration for this paper is that any private or research-based therapeutic usage of a device based on the presented exemplar should always fall under the guidance of a qualified audiologist or similar clinical professional. The necessary backgrounds for these primary aims are as follows.

Digital hearing aids and tablet-based devices: the current scene

Current behind-the-ear (BTE) digital hearing aids employ various forms of DSP to provide the following features for many available hearing aid models: self-adjustment capabilities including multiband wide dynamic range compression; acoustic feedback control circuitry and effective noise reduction algorithms (including via phase cancellation); spectral shifting (especially frequency lowering); individualized calibration via multiband gain adjustment for discrete frequency bands throughout the wearer's auditory spectrum; and wireless capabilities.¹⁻³

Despite the rapid development in hearing aid technology since the introduction of DSP in 1996, the limitations of current devices are still recognized,¹⁻⁶ with significant numbers of hearing aid wearers continuing to express dissatisfaction in key fields such as clarity, sound naturalism, ability to hear soft sounds, and degree of acoustic feedback/buzzing/whistling experienced (dissatisfaction rates above 20% are reported for several fields).^{1,6} The imperfect nature of current BTE digital hearing aids is not surprising given that every amplifier has response limitations (*e.g.*, in relation to frequency or bandwidth, phase and slew-rate), and such limitations are to be especially expected within the confines of miniaturization. Additionally, the close proximity between speaker and amplifier for digital hearing aids makes adverse acoustic feedback effects inherently likely which in turn necessitates feedback countering technology, the effectiveness of which can vary for even the most sophisticated of digital hearing aids, depending on the environmental circumstance. Indeed, many aspects of a comprehensive 1996 review⁴ into acoustic feedback and other audible artifacts for hearing aids remain relevant for today's devices. Thus, while current BTE and other digital hearing aids are technologically impressive, generally perform well and help hearing impaired people worldwide, their *perfect* performance cannot be expected, with the not uncommon complaint made by users, that the device amplifies sounds to an adequate level of perceived loudness yet does not meet expectations of improved audible clarity, involving a complexity of issues that are difficult to address within the above-identified miniaturization confines.

With the above in mind, others have correctly foreseen that the next revolution in hearing aid technology will involve wireless technology

(e.g., Bluetooth) within portable computers and hands-free cell phones transmitting to an earpiece^{1,3} and, while such a *revolution status* has yet to be achieved, the progressive immergence of a limited variety of tablet-based hearing aid tools has since commenced (e.g., assistive listening device connectivity/streaming, *ear-assisting apps*, tablet-based hearing aid programming).^{7,8} The practical and easy-to-follow nature of the exemplar to be presented also inherently supports the likely future wider-spread availability of tablet-based hearing aid solutions within mainstream healthcare, whilst also providing a basis for student (research and learning) projects within biomedical engineering.

Within above-such solutions, the available processing power and advanced combinations of data acquisition and DSP techniques theoretically allow for a substantive data epoch *record* → *frequency domain process* → *play-back* routine in a continuous, effective real-time manner (at-least within the acceptable time delay limits⁹⁻¹¹ collectively indicated by others). Thus, tablet-based devices potentially offer clear technological advantage when compared to the spectrally-limited DSP capabilities and approaches of many conventional BTE hearing aids that may for example simply isolate and statistically process filter-selected time-based envelopes, or rely on simple environmental classifiers for some DSP outcomes such as noise reduction.^{1,12,13} As a means of highlighting the substantive DSP opportunities available, a frequency domain process of focus for the presented exemplar is that of spectral shifting (especially frequency lowering relevant for hearing-impaired individuals with limited access to higher frequency sounds), for which several techniques exist within the literature.^{12,13}

The educational scene

Bioinstrumentation is a second year course within the School of Allied Health Sciences of Griffith University's Health Faculty (Australia). The course has a student cohort size of approximately 150 and is prerequisite (provides a physical basis) for a subsequent Bioinstrumentation-in-Physiotherapy course involving the clinical application of various electrotherapy modalities. The showcased course also provides an instrumentation platform for a subsequent Biomechanics course and select higher-level student research projects.

The teaching of any physics/instrumentation-based course to health science students carries its own rewards and challenges. Despite the recognized challenges, Bioinstrumentation has an established track record of positive student outcomes which are attributed to the facts that course teaching and assessment strategies cater for a range of student learning styles, are delivered in a relevant health context, and build upon pedagogical approaches¹⁴⁻¹⁶ that have proven successful for the teaching of physical science topics to similar student cohorts. These attributions have ultimately lead to a multifaceted, authentic^{17,18} assessment approach with an emphasis on practical skill development and delivery of vocation-related instrumented projects, with project delivery facilitated by staircased skill development.¹⁴ Assessment-for-learning^{18,19} items employed within Bioinstrumentation are summarized in Table 1.

Simeoni¹⁴ critiques the multifaceted assessment approach of Bioinstrumentation and summarizes its official on-line 2012 student

Table 1. Multifaceted assessment items for the showcased Bioinstrumentation course at the time of Simeoni's¹⁴ study (assessment has been slightly refined since that study).

Assessment task	Weighting	Item description
Electronic laboratories reports	25%	A total of eight 3-h laboratories which develop: electronic circuit design, construction and diagnostic (via oscilloscope and digital multimeter) skills; an understanding of electronic sensor operation and a practical ability to incorporate sensors into compatible electronic circuitry; signal amplification skills; signal processing skills (e.g., filtering and Fourier analysis of biosignals); and computer interfacing/data acquisition skills. Final laboratories are largely self-directed and represent a culmination of semester skills learnt. Non-compulsory tutorials that aid student understanding of course theory are also integrated into the laboratory schedule.
Computer laboratories	10%	Six 1-h computer laboratories introduce students to the National Instruments Labview graphical computer programming language by the progressive develop of heart rate analysis and reaction time computer programs. Skills learnt are taken into the above Electronic Laboratories for further development and application within projects involving computer interfacing (controlled by Labview programming).
Journal article report	10%	Students are independently required to locate and identify a recent physiotherapy- or exercise science-related scientific journal article of interest and which utilizes some form of bioinstrumentation. Students are required to submit a 1000 word critique of the article, highlighting the instrumentation reported. An investigatory component of the report requires students to research sensor/instrument: cost, supplier, delivery time, technical specifications, study selection rationale, and applications (for alternative studies). This investigatory component provides students with a realistic sense of the processes involved with instrumented research project design. Thus, the investigatory component also provides students with foundation skills for their own research project in the future (e.g., if undertaking an honors project or research higher degree).
Summative quiz	15%	This assessment item provides early feedback. A post-quiz session is dedicated to reviewing the quiz and students are invited to one-on-one quiz reviews.
End of semester examination	40%	Multiple choice examination questions are utilized and designed with a mixture of simple completion, multiple completion and relationship analysis questions. Question construction techniques are adopted so as to optimize the relevancy and focus of questions. Both concept- and calculation-type multiple choice questions are included within the above to assess knowledge application.

evaluation survey from the time of that study: 83% of respondents agreed or strongly agreed that assessment and its feedback were fair, clear and helpful, while 80% of respondents agreed or strongly agreed that the course was well organized, and that teaching of the course was effective in helping student learning. These percentages are relatively high for a physics/instrumentation course undertaken by health science students, with the 33.3% survey response rate, while meaningful, reflecting the institution-wide challenge of engaging students with official on-line evaluations. The above evaluation scores were again supported in 2014 with values of 90 and 85%, respectively.

Examples of vocation-relevant instrumented, computer-controlled devices/projects that have been incorporated within Bioinstrumentation include: reaction timer, piezoelectric pulse sensor, load cell-based grip strength dynamometer (Figure 1A), first-principles electromyogram (EMG) machine developed from the operational amplifier level (Figure 1B), instrumented drop-test device (Figure 1C) to measure the acceleration due to gravity (which educationally links to the students' first year Biophysics course curriculum, as well as providing gate triggering and impact/reaction measurement skills relevant for Biomechanics), force-measuring athletics starting blocks (Figure 1D), tennis racket with vibration sensor, and a range of miscellaneous other sensor interfacing demonstrations.

Projects for which semester-developed skills staircase towards involve a significant degree of student self-direction, and where possible are enhanced by complimentary lectures of high student interest. For example, before undertaking the EMG project of Figure 1B, students receive a guest lecture from a hospital-based neurophysiologist who delivers an instrumentation-focused presentation on the use of EMG within intra-operative neurophysiological monitoring during catheter laboratory spinal surgery, and the use of electroencephalogram (EEG) for diagnosing obstructive sleep apnoea within polysomnography. Other guests (physiotherapist and biomechanist) also deliver lectures on preludes to instrumentation within the physiotherapy and biomechanics professions.

For standard course lectures, a recognized need exists to improve upon student engagement, which more generally reflects a growing sector-wide challenge of engaging students with traditional lecture-based delivery. This challenge has recently been positively confronted within a Health Faculty via a flipped classroom approach.²⁰ Within such an approach, lecture time is devoted to student-centered activities, where for example students may assume the responsibility of classroom direction through student-lead enquiring and discussion. Accordingly, integrated within the most recent running of Bioinstrumentation is a flipped classroom approach to enforcing key instrumentation principles via a student inquiry session into the presented tablet-based hearing aid exemplar.

Materials and Methods

Instrumentation

A Microsoft Surface Pro 2 256 GB 10.6 inch tablet with 8 GB RAM and Intel(R) Core(TM) i5-4300U CPU (1.90/2.50 GHz) processor, running National Instruments (NI) Labview 2013 Full Development system, was utilized as the primary hearing aid processor. Connected to this processor via its USB connection port was a NI myDAQ data acquisition device. In turn connected to the NI myDAQ audio input (3.5 mm stereo jack) was a Rode stereo videomic pro cardioid microphone (12.60 mV @ 94 dB SPL sensitivity, 200 Ω output impedance, and selection of +20dB gain level control). To provide a wireless option, an Audiomate AM811T wireless transmitter (2.4 GHz radiofrequency employing FHSS/GFSK digital modulation technology) was connected to the NI myDAQ audio output stereo jack with transmission to an Audiomate AM12R receiver. The Audiomate transmitter/receiver system specifies a minimum signal-to-noise ratio (SNR) of 80 dB, 20 to 20 kHz bandwidth, 360° omnidirectional transmission, reception range up to 30 m, and a rechargeable battery usage time of approximately 3.5 h. Bose QuietComfort 20 Noise cancelling earphones, with incorporated slim-line noise cancelling module, were connected to the audio-output of the receiver. The tablet and add-on components of the tablet-based hearing aid were fitted neatly into a standard portfolio for the specified tablet. A schematic diagram and corresponding actual experimental wireless



Figure 1. Example Bioinstrumentation student computer interfacing projects/activities. A) Instrumented grip strength dynamometer; B) first-principles electromyogram system; C) gravitational acceleration measurement device based on drop-test analysis; and D) force-measuring athletics starting blocks demonstration (bench-top usage for display only).

Table 2. Itemized component costs for tablet-based hearing aid with two primary microphone options distinguished.

Component	Cost (\$AUS)	Component	Cost (\$AUS)
Microsoft Surface Pro 2 256 GB tablet	1200	National Instruments myDAQ	200
National Instruments Labview 2013 full development software	1200	AudioMate AM8112 wireless digital audio transmitter/receiver set	60
Bose QuietComfort 20 noise cancelling earphones	400	Carry case/portfolio	50
Rode stereo videomic pro microphone	280	Total	3390 or 3190
or smartLav+ microphone (with TRRS to TRS adapter)	80		

set-up are shown in Figure 2A and B, respectively.

Various alternative system configurations were also constructed to demonstrate system variations associated with cost *versus* performance, portability, style, and functionality. Example variations include the use of the following component alternatives: Avantree Priva/Saturn low latency (32 ms) Bluetooth transmitter/receiver system; Bose SoundTrue and SoundLink Bluetooth headphones; a non-wireless option with direct headphone connection (to NI myDAQ audio output); a discreet Rode smartLav+ microphone (omnidirectional, 17.80 mV @ 94 dB SPL sensitivity, 0 Ω output impedance); and a Smart MYK directional shotgun microphone (hypercardioid, 200 Ω output impedance, +15 dB gain boost).

Data acquisition

The purpose-designed Labview program was set to acquire the voltage signal from the audio input of the NI myDAQ using a range of f_s values, from 40 to 300 kHz, and range of epoch lengths, from 500 to 10,000 points, where epochs were collected in a continuous sampling mode (*i.e.*, contiguous n -point epochs were continuously collected at the specified f_s). The NI myDAQ analog-to-digital and digital-to-analog converter voltage ranges were both set to ± 2 V in accordance with the acquisition device's voltage range limits.

Digital signal processing

The acquired stereo voltage signal was split into left and right data streams within the Labview programming environment. Each stream was then directed to a user-selectable and adjustable (via the graphical user interface of the designed Labview program) ten-band equalizer. The equalizer was based on a frequency band selection principle whereby the data stream was multi-replicated, with each replication (one for each band) separately fed to a third order Butterworth band-pass selection filter. The gain-controlled outputs of all filters were then recombined for the left and right streams. The default frequency cut-off limits for the ten bands were <125, 125-250, 250-500, 500-750, 750-1000, 1000-1500, 1500-2000, 2000-4000, 4000-6000 and >6000 Hz. These default band limits were additionally adjustable to suit the audiometric response of the user. The equalization (multiband gain control) approach was an expansion of a three band, single stream approach²¹ applied to the iPhone[®]. All bands for the present study allowed for a user-adjustable gain from 0 to 40 dB, except for the lowest two bands which had an extended gain range of -20 to 40 dB.

Each (optionally) equalized left/right datum stream was then directed to a user-selectable and adjustable spectral shifting (frequency lowering) subroutine. This convolution-like frequency lowering subroutine involved a Fast Fourier Transform (FFT) of the stream followed by compression (*e.g.*, 2-to-1 and 3-to-1 point averaging compression) of the FFT spectrum above a selected compression frequency threshold, f_c . To maintain spectral resolution characteristics of the original stream, the compressed FFT spectrum was also right-buffered (to maintain original FFT length), by filling the spectrum with appropriate nulling values in line with FFT baseline values, to compensate for FFT data points otherwise eliminated between $f_c + (f_{max} - f_c)/c$ and f_{max} , where f_{max} is the maximum frequency of the FFT spectrum and $c=2$ for the example case of 2-to-1 point compression (and so on for other levels of compression). Like other identified user selectable program parameters, the choice of frequency lowering parameters such as f_c and level of compression (*e.g.*, 2-to-1 or 3-to-1), are available to the user during the run-time of the program. Inverse FFT reconstructed each stream back to the time domain.

Each datum stream was finally auto-rescaled to ensure maintenance of initial overall sound intensity. Rescaling was achieved via a normalization process involving the application of a multiplicative ratio of (pre- and post-processing) data average root mean square (RMS) values. A user-controlled overall multiplicative factor was also subsequent-

ly applied to the combined streams which served as the user's audio volume control. This final volume scaling was limited to ensure an output voltage limit of ± 2.0 V (to match the previously-stated NI myDAQ range).

Audio output validation

For the above configurations, reconstructed sound output was quan-

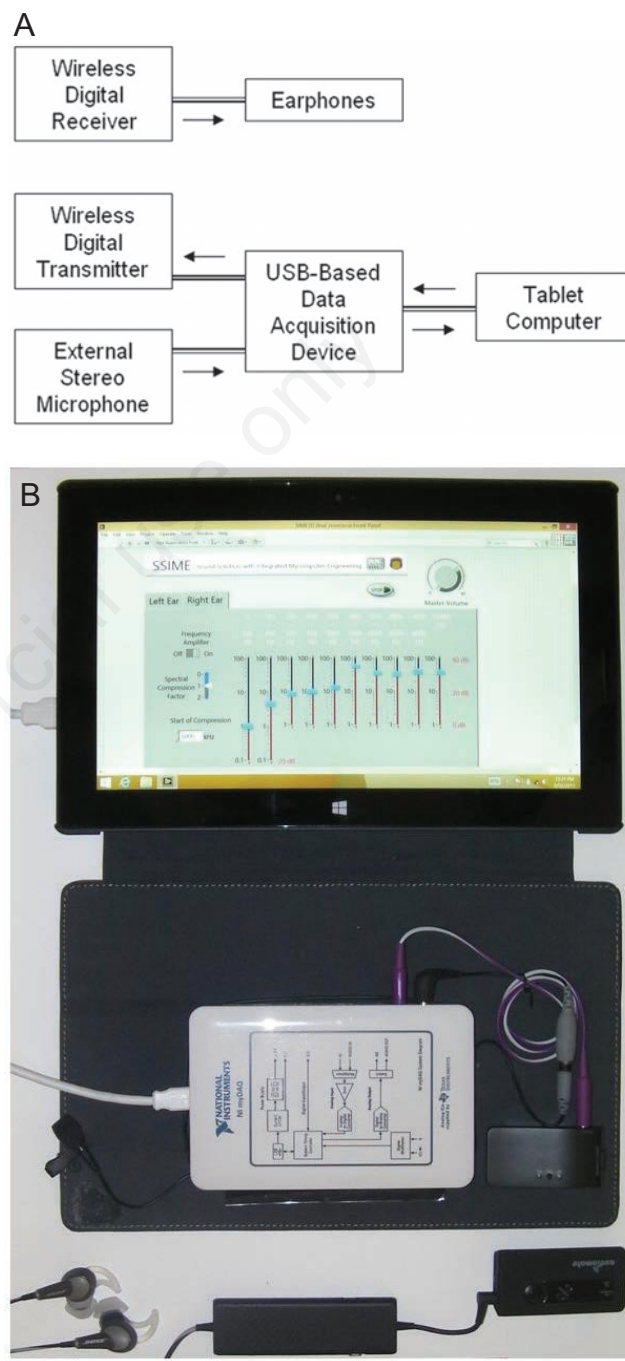


Figure 2. A) Schematic diagram of experimental set-up; and B) developed hearing aid configuration formed around a Microsoft Surface Pro 2 256 GB tablet. For B), all components are neatly fitted into a standard tablet portfolio; the Bose QuietComfort 20 in-ear earphones include an additional slim-line noise cancelling module shown between the earphones and Audiomate AM12R receiver; the discreet Rode smartLav+ microphone configuration option is shown.

titatively assessed via a SNR calculation that was based on a variant of the total harmonic distortion plus noise (THD+N) analysis approach and which allowed for standardization. This approach utilized pure tone 2000 and 6000 Hz sound signals produced from a GW GFG-8020G sinusoidal function generator connected to a 0.25 Ω , 8.0 W loudspeaker in a controlled and closed laboratory environment (not a formally sound treated chamber) with an average ambient sound level of 32.5 \pm 0.1 dB, as measured by a Digitech QM-1589 sound level meter. The generated pure tone test signals were set to a 70.0 \pm 0.1 dB average intensity at the location of the tablet-based device microphone, at which the test signals were directed. The tablet-based device's (analog) audio output was then connected (wired) to the audio input of a second standard recording computer, also running Labview, for SNR analysis. The analysis of each outputted signal involved the separate integration of the harmonic peak and the remaining components of the signal's Fourier spectrum (11.025 kHz bandwidth), and then using the two integrated values within the standard SNR formula. This procedure was repeated with the tablet-based device bypassed (*i.e.*, direct recording of the sound source by the recording computer utilizing the former device microphone). A detection threshold was set that ensured the preservation of SNR to within -2.5 dB of the original sound source in the absence of any active noise reduction process or tablet-applied gain, with the threshold value determined from the combination of sound level (and thus input SNR) variation uncertainty, and accepted THD tolerances for the electroacoustic testing of hearing aids.²²

Processing time delay was determined via software coding that retrieved an internal clock status at the instances of data acquisition

read and write commands, and then calculating the difference in these clock values. Subjective sound quality assessment naturally also formed part of early prototype development.

Learning and teaching implementation and assessment

A two hour traditional lecture was replaced by a flipped classroom session that centered around the exemplar's technical, design and functional aspects. Following a brief setting of the digital hearing aid scene by the lecturer (including speaking through the exemplar with its output connected to the lecture theatre's audio system), students were asked to form small groups, with the group work sequence described by the utilized flow diagram of Figure 3.

At the end of the flipped classroom session, students were asked to rate their level of interest and engagement using a standard 5 point scale, and the same evaluation question was completed for traditional course lectures (overall).

Results and Discussion

Audio output validation

The tablet-based device met the -2.5 dB SNR preservation threshold for the primary microphone configuration. The variation to standard THD+N analysis, while subject to input sound level measurement uncertainty, allows for more readily identifiable input *versus* output

Your Flipped Classroom

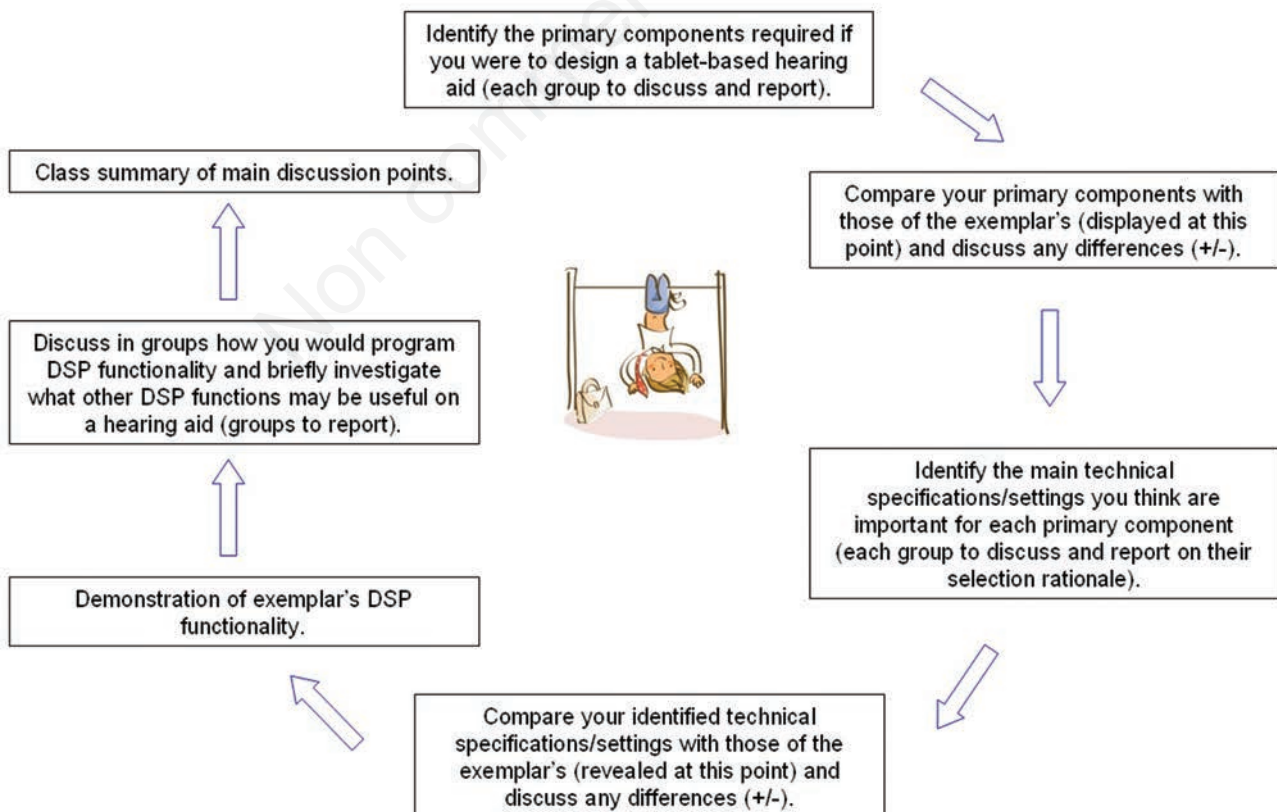


Figure 3. Flipped classroom approach flow diagram. DSP, digital signal processing.

performance quantification (compared to THD-based methods that can be difficult to compare between systems). Whilst the recorded Fourier spectra of collected waveforms sharply retain high SNR without appreciable harmonic distortion, the observed presence of low-level broad spectrum noise, only evident by logarithmic scaling, indicates the potential opportunity and benefit of active noise reduction techniques in the frequency domain.

The measured average processing time delay for $f_s = 200$ kHz plus 2000 point epochs, with mid-range compression and multiband gain/equalization applied, was 2 ms at epoch play-back (non-wireless mode). This processing delay falls comfortably within the lower limit of recommended time delays (5.0 to 20 ms) required to avoid adverse effects on sound reproduction.^{9,11} Based on these quantified timing results, opportunity exists for significant expansion upon the employed methods of DSP (discussed later).

No adverse feedback or similar effects were observed in-practice for the extended amplification range offered by such a device, as inherently expected because of the separation of microphone and amplifier. Audio output validation in relation to the device's effectiveness towards improved hearing quality (*i.e.*, a clinical validation) does not fall within the scope of the present study.

Add-on components

Compared to light-weight BTE digital hearing aids, the use of add-on components such as the NI myDAQ naturally detracts from the tablet-based device's portability. However, the use of these add-ons is advantageous for a student project situation. For example, the NI myDAQ usage offers: equipment familiarity and simplicity for the student cohort; greater data acquisition control (*e.g.*, continuous acquisition mode and f_s selectability at ≥ 100 kHz); and flexible connectivity options that enable students to readily trial configuration variants in conjunction with specification-based selection deliberations.

In relation to a trial of microphone variants, it should be noted that a rigorous performance comparison of hearing aid microphone types also does not fall within the scope of the present study, particularly since such a comparison represents a comprehensive area of research already well established within the literature.²³⁻²⁵ However, because of the device's convenient connectivity, various microphones may be trialed by students to demonstrate known microphone results for hearing aids (*e.g.*, a microphone's type can greatly influence its associated SNR intelligibility threshold, with omnidirectional microphones typically being inferior to directional types due to environmental noise susceptibility issues, but with exceptions in some circumstances).²³⁻²⁵

Wireless microphone variants can also be conveniently configured in a manner similar to that of the wireless earphone connection or, a purpose-bought wireless microphone could also just as easily be incorporated for such wireless intensions. For the wireless earphone options trialed, a mild perceivable play-back delay occurred for the method-specified *low* latency (32 ms) Bluetooth transmitter/receiver system (as expected based on previously stated acceptable time delays). In contrast, the method-specified Audiomate AM8112 system, employing FHSS/GFSK wireless digital modulation technology, avoided any appreciable play-back delay when the tablet-based device was configured in wireless mode.

Utilization of arguably unnecessary best-on-market noise cancelling in-ear earphones is perhaps an overstatement of flexibility, but adds to student discussion of specification-based selection rationale (and provides undoubted relatively high audio performance).

Data acquisition parameters

The application of: i) continuous acquisition of contiguous data epochs; ii) substantive frequency domain DSP; and iii) play-back, of collected audio data so as to achieve effective, real-time play-back without discernible delay and with a clarity that comparatively enhances or

at least matches the word recognition capabilities provided by current devices, requires a balanced combination of interdependent and complementary data acquisition parameters. For example, the epoch length for a given f_s determines frequency domain resolution and processing time for each collected data epoch, which together may influence: the overall reconstructed sound quality, the degree of play-back delay, and the potential introduction of added adverse reconstruction artifacts (*e.g.*, noise peak at the epoch reconstruction frequency and spectral leakage²⁶ brought about by the inherent windowing of epochs).

On a rudimentary level, a relatively fast sampling requirement may be expected within the above real-time process; the Nyquist limit is after-all a minimum ideal limit and many will routinely advocate the use of a f_s that is several, rather than just two, times the theoretical upper band limit in a non-ideal, in-practice situation. Ordinarily f_s values from around 22 to 48 kHz are common default industry standards for general acoustic recording, and the f_s value employed by at least one leading hearing aid brand is 32 kHz²⁷ which is appropriate for human speech in terms of the Nyquist sampling theorem requirement. However, based on the aforementioned balance of device acquisition parameters, Nyquist does not alone suffice to select the f_s for the tablet-based approach: for example, $f_s = 40$ kHz plus 10,000 point epochs yields an unacceptable play-back delay, while $f_s = 200$ kHz plus 2000 point epochs yields excellent play-back timing and sound quality but the resulting broad Fourier resolution (100 Hz) and bandwidth (0.1 MHz) may result in reduced frequency domain DSP effectiveness/efficiency (example presented later). An effective device compromise was found to be $f_s = 50$ to 100 kHz plus around a 2000 point epoch length, dependent upon one's processing outcome priority.

Cost of device

The breakdown of off-the-shelf component costs (rounded, Australian dollars) for the developed device is given in Table 2.

As indicated by Table 2, total device cost is reduced by \$200 when using the more portable Rode smartLav+ microphone (as per Figure 2B), rather than the larger Rode stereo videomic pro cardioid microphone, the use of which trades-off miniaturization for microphone performance. Total costs compare favorably with the premium price of a pair of high-end BTE digital hearing aids, which in Australia can exceed \$10,000 (\$7000 EUR).

Digital signal processing considerations

The showcased exemplar highlights the potential for such devices to provide continuous data epoch (record \rightarrow DSP \rightarrow play-back) processing in effective real-time, and with substantive frequency domain DSP. For example, while non-linear spectral compression is a known form of frequency lowering,^{12,13} the overall manner of non-linear frequency lowering applied here, *i.e.*, point-by-point, convolution-like approach that offers flexibility of application across the frequency spectrum in terms of compression level and type (*i.e.*, non-linear or otherwise), exceeds the frequency lowering capabilities of commercial BTE hearing aids.

When spectral shifting was extended to the lower frequency range, a reconstruction *mechanical sounding* artifact was evident for some acquisition configurations (just as conventional BTE digital hearing aids operating at or beyond their regular DSP setting limits may produce artifact or distortion). This artifact is attributed to cases of relatively broad DSP frequency domain resolution (*e.g.*, encountered at very high $f_s \approx 200$ kHz), thus again highlighting the on-going trade-off between parameter settings. *Viz.*, a very high f_s and broad frequency resolution are advantageous for some aspects (*e.g.*, spectral smoothing) but then the resolution can in a straight forward manner be made finer (*e.g.*, by decreasing f_s and/or increasing the number of epoch points) to remove said artifact.

The use of Butterworth band-pass filters within the employed ten-

band equalizer (multiband gain control) was for convenience and demonstration of principle (the student cohort had previously developed a NI Labview program to filter EEG data via Butterworth filtering in laboratories). This filtering approach also allows the number of bands to be easily increased without appreciable compromise of computation cost. However, a convolution approach to equalization is just as feasible and could be implemented together with the convolution-like approach to spectral shifting (leading to a truly multiband equalization approach with the number of bands limited only by the resolution of the Fourier spectrum). Similarly, advanced frequency domain active noise reduction and speech detection enhancement techniques (e.g., noise reduction through phase randomization, predictive coding, cepstral filtering, and frequency domain peel-back variants)^{1,28,29} could readily be incorporated within an expanded student project, especially for biomedical engineering students learning relatively advanced DSP techniques.

No appreciable spectral leakage effects brought about by epoch windowing of the time series signal²⁶ was detected, though the optimization of windowing method (e.g., Blackman, Hanning, rectangular or other) is certainly an area worthy of future investigation.

Student engagement and learning

Engagement/interest evaluation scores for the flipped class session were expected to be higher than that of traditional lectures, given that the flipped class involved a *high-impact* one-off session of inherent modern technological interest to students, and positive outcomes are known to arise when technological applications are effectively integrated with Bloom's taxonomy of educational objectives³⁰ (see for example a current educational best-practice tool, the *pedagogy* wheel,³¹ designed for the iPad® and also applied within a flipped class approach³²). That is, the educational approach taken with the tablet-based hearing aid represents technologically-based, activity-centered learning that enhances capabilities, motivation and cognitive understanding through the processes of application, evaluation, creation and analysis. Accordingly, chi-squared analysis reveals a statistically significant ($\chi^2=4.1$, $P<0.05$, $df=1$) increase in the number of positive survey respondents when applied to the two analysis items of the flipped session and traditional lectures. In addition to the above positive engagement/interest outcome, the flipped class session complemented the multifaceted assessment and learning approach of the course¹⁴ and demonstrated a teaching strategy that encourages students to constructively enquire and rationalise technical specifications and design. However, while the session undoubtedly sparked enthusiasm in some students (e.g., based on extra post-session discussion), the session also challenged students, with the challenge positively embraced by many but also reluctantly embraced by others who admitted preference towards a traditionally structured lecture, as reflected by the modest significant chi-squared analysis outcome (which in itself is a positive outcome for a multifaceted educational approach designed to *offer something for everyone*). Students also reported that the flipped classroom session aided the attainment of an appreciation of, and broader perspective towards, computer interfacing and the technical elements required across the entirety of an instrumentation project.

The manner in which the exemplar device was incorporated within instrumentation teaching of course represents just one of several possible means of incorporation (e.g., full project implementation via an assignment for higher-level biomedical engineering students is another such means).

Conclusions

A tablet-based hearing aid configuration, designed as a student proj-

ect exemplar and which continuously records, substantively processes, and plays-back sound in an effective real-time manner, has been developed and integrated into a Bioinstrumentation course, leading to positive measures of student engagement and learning within a flipped-classroom scenario. The configuration employs a relatively high sampling frequency to acquire the sound signal of interest whilst applying an advanced spectral shifting technique together with conventional frequency band equalization. The approach utilizes optional add-on data acquisition, high fidelity microphone and wireless transmission accessories, which offer advantages in relation to student familiarity, data acquisition control, and flexible connectivity for configuration variants that may be trialed following specification-based selection deliberations.

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