Using Acoustic Emission Technique to Detect Termite Activities in Wood: Laboratory Experiment

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Abstract

This experiment studied and analyzed termite activities in wooden blocks. The purpose of the study was to develop and test a strategy for isolating termite acoustic emissions (AE) from background noise. This task is not trivial, and therefore the achievement of a clean signal that can be directly associated with termite activities is a good outcome. It is an important step toward achieving an accurate, nondestructive system to detect termite activities in wood. The wooden blocks were immersed in jars that were filled with termites to expose the blocks to termite infestation. The termites' AE, due to their activity in the wood, was recorded using microphones that were fitted in the center of each wooden block. The Cool Edit Pro 2.1 (Syntrillium Software Corporation) sound recording application was used to filter the recorded AE signals. The filtered AE signals were then analyzed using the Matlab application. The wooden blocks experiment showed that termite activities in the wood could be detected using AE recording. Termite activities are clear and detectable in the 4.5- to 5-kHz range of frequencies. Results could also assist in defining the termites' AE signature, to some extent, by analyzing the generated sound due to termite activities in the wood. A clean termite-related AE was successfully extracted from the general AE in the wooden blocks using Matlab R2015a tools.

This experiment aimed to prove the ability of utilizing the Matlab R2015a application and Cool Edit Pro 2.1 (Syntrillium Software Corporation) sound recording application as effective tools to acoustically and nondestructively detect termites in timber in service. This experiment could assist in defining the termite acoustic emission (AE) signature by analyzing AE signals that were generated due to termite activities in timber in service. Defining termites' AE signatures will improve the quality of the current termite detection systems.

Termites have been labeled as invasive (Scheffrahn et al. 2009, Evans et al. 2011) due to the severe damage they cause to wooden structures and timber in service. Evans et al. (2013) added that, during the past 45 years, aggressive termite species have increased in number from 17 to 28. All invasive termite species have three common characteristics that add to their pest status: (1) wood eating, (2) nesting in wood, and (3) the ability to produce secondary reproductives (Evans 2011). In particular, subterranean termites are a major threat to timber in service and other important infrastructure, such as underground telephone cables, in Victoria and across Australia (Standards Australia 2000, Creffield 2005).

Acoustic approaches have been used to detect termites in wood (Scheffrahn 1993, Mankin et al. 2002), hidden insects in their environments, larvae in tree trunks (Mankin et al. 2008a), and even insects in soil (Mankin 2000, Zhang et al. 2003, Siriwardena et al. 2010). Siriwardena et al. (2010) conducted an experiment to identify the Red Palm Weevil (RPW) larvae's acoustic signature. Matlab was used to analyze RPW recorded signals. To obtain accurate results of the RPW digital signature, RPW activities were recorded and their signal samples analyzed and stored based mainly on key signal coefficients. A signal processing circuit, including a band-pass filter (BPF), was used to filter the RPW sounds from the background noises and to amplify the resultant filtered signal (Siriwardena et al. 2010). They used a BPF with a frequency band (0.8 to 2.5 kHz) that matched the RPW activity frequency range (Siriwardena et al. 2010).

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Insects usually produce 3- to 30-ms impulses of 0.2- to 5-kHz sound temporally grouped or patterned together in short bursts as they hide inside soil, wood, or stored food. In most cases, AE can be an easier way to detect and identify these sound bursts compared to traditional visual detection methods (Mankin 2013). Mankin (2013) added that AE not only enables inspectors to determine that insects are present but also may enable identification of the presence of target species. Although it was proven by several studies that developing spectral profiles of pulses and filtering to separate recorded insect sounds from background noise helps identify insects, structural attenuation and resonances add difficulties to the signal analysis and reduce the identifiability of the signal as it passes through a medium (Mankin et al. 2008b).

Insect detection and monitoring started using acoustic recording and playback technologies in the early 1900s (Mankin 2011, 2012). For insect management, acoustic recording studies have been conducted to attract and trap insects (Walker 1988, 1996; Mankin 2012). Sounds generated due to termite activities could be identified over a distance of 1.8 m on a board in the laboratory; however, background noise levels may affect the distance of termite detection (Mankin et al. 2002, 2008b). If the background noise contained energy at the resonant frequencies of rigid, fibrous structures, which are generally available in trees and wood structures, it would be more difficult to distinguish insect sounds from background noise (Mankin et al. 2008a). Monitoring termite activities using acoustic devices became one of the more successful insect acoustic monitoring activities (Indrayani et al. 2007), and several companies now distribute termite acoustic detection instruments (Mankin 2011).

At a frequency range of less than 10 kHz, it was proven that a greater range of acoustic detection was achieved during detection of hidden termite activities in urban trees (Mankin et al. 2002, Martin and Juliet 2013). At the University of California, Lewis et al. (2011) conducted an experiment for 11 months to monitor termite activities in a wooden structure under ambient conditions. Lewis et al. (2011) commented that quantification of vibrations using AE technology has proven to be a useful and successful method of detection in the case of wood that was naturally infested with drywood termites. Drywood termites generate vibrations in wood that sometimes can be detected directly by the human ear. However, usually amplification is required for detecting termite sounds (Stuart 1988, Kirchner et al. 1994).

Termite feeding and foraging activities are the main source of detectable sound (Fujii et al. 1998); nevertheless, workers' and soldiers' head banging behavior can be heard as well (Lemaster 1991, Beall 2002). In laboratory settings, vibrations made by drywood termites can be successfully detected, at least 80 percent of the time, by available AE devices (Lewis 1991, Lewis et al. 1991, Scheffrahn 1993). Termite activities in the wood, such as their movement within the wood and their pulling of wood fibers, generate AE events (Lewis 1991, Lewis et al. 1991, Scheffrahn 1993). Drywood termite activities can be detected within 8 cm across the grain or 240 cm along the grain from the termite infestation area (Scheffrahn 1993, Lemaster 1997, Lewis et al. 2011). It was confirmed by different researchers that termites communicate using substrate vibrations (Evans et al. 2005, Inta 2007, Evans 2009).

Figure 1.—Laboratory termite activities in wooden blocks: (A) recording termite infestation on the wooden samples with six microphones labeled from 1 to 6 inserted into the jar filled with termites and (B) sample wooden blocks with fitted microphones labeled 7 to 12 inserted into the termite-free jar to be used as a control.

The purpose of the study was to develop and test a strategy for isolating termite AE from background noise.

Experiment

Termites used in this experiment are *Coptotermes frenchi*, the Australian subterranean termite. Termites and their mound material were collected from the natural environment in Northern Territory, Australia. They were kept in a conditioned room at a temperature set to 32°C and relative humidity set to 55 percent. The wood type used in this experiment was Monterey pine (*Pinus radiata*). It is considered to be the dominant tree species in Australian plantation estates (Lindenmayer and Hobbs 2004).

This experiment explored termite activity in wood. The wood samples used in this experiment were softwood Monterey pine. Wooden blocks (20 by 20 by 20 mm) were used to increase the possibility of detecting termites' infestation sounds. The blocks were inserted into jars that contained termite mound material (*C. frenchi*) within. The Cool Edit Pro 2.1 application, an audio recording technique, was used to collect and sense termite activity in the wooden blocks. A BPF was set by using the Audacity audio application, and the recorded signals were filtered. The

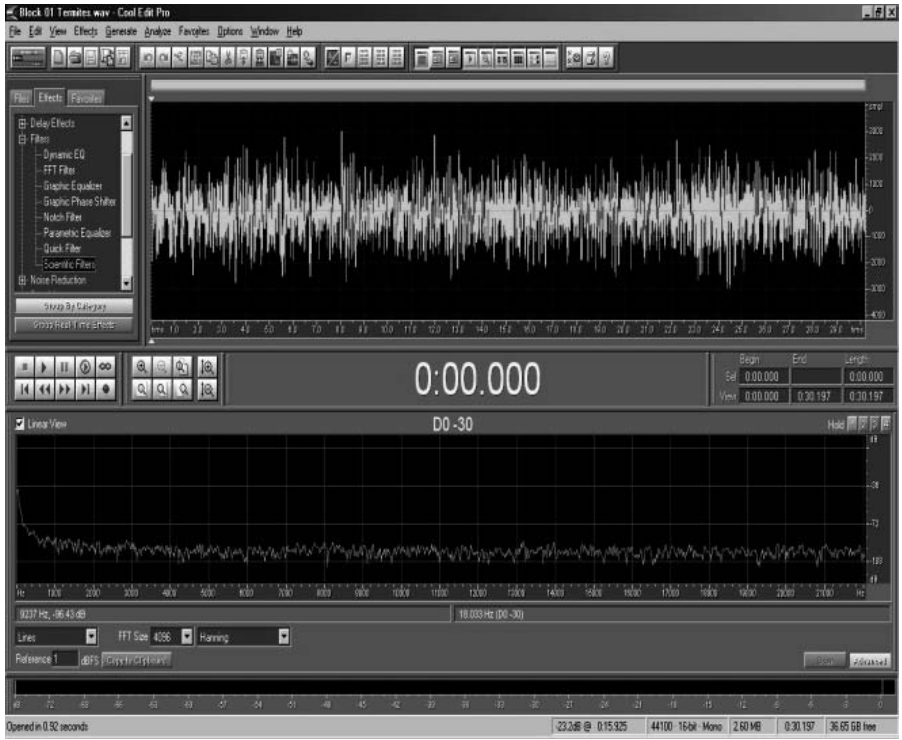

Figure 2.—Original unfiltered input signal recorded displayed by Cool Edit Pro 2.1.

filtered signals were analyzed to detect termite feeding sounds in isolation from most other background noises.

Methods

This experiment was conducted using 12 small blocks of wood with microphones inserted into the center of each block. The blocks, with the microphones, were inserted into two jars. One of the two jars was filled with termite mound material with captive termites (*C. frenchi*) within them, while the other jar was filled by termite mound material with no termites. The six microphones labeled from 1 to 6 were inserted in the first jar with the termites, while the other six,

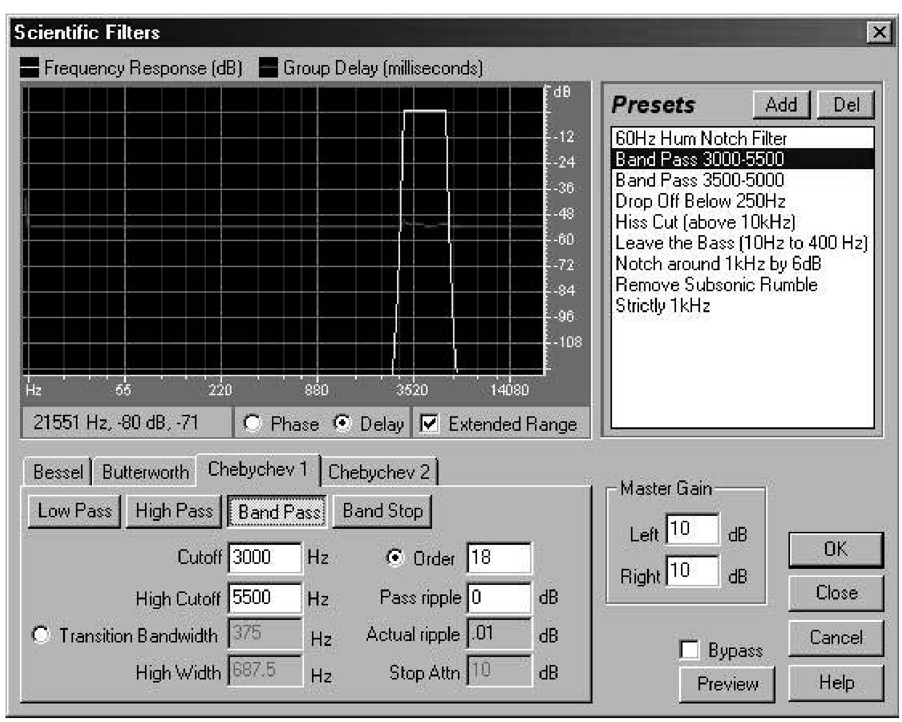

Figure 3.—Band-pass filter 1 (BPF1), which passes the 3- to 5.5-kHz frequency band designed by Cool Edit Pro 2.1.

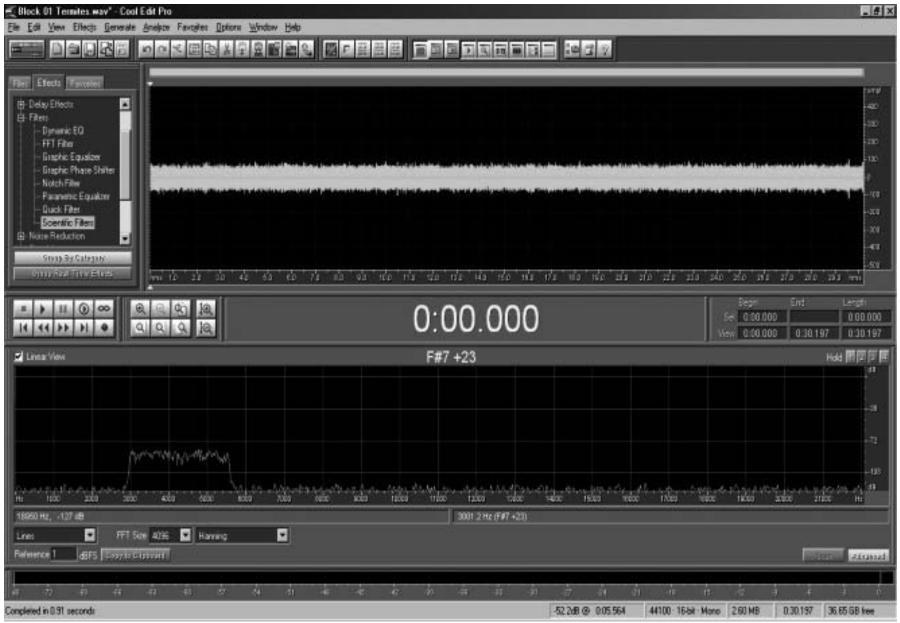

Figure 4.—Result signal after applying band-pass filter 1 (BPF1) displayed by Cool Edit Pro 2.1.

labeled 7 to 12, were inserted in the second termite-free jar to be used as a control. All 12 microphones were connected to sound cards, and termite activities were simultaneously recorded using a laptop computer. After placing the wood blocks in the jar that was filled with termites, a grace period of 1 day was allowed before the start of the recording to make sure that termites started naturally to feed on the wood blocks and that they were in their steady state. Figure 1 shows the experiment setup and the recording system used.

Several recordings (10 replicates) of 30-second duration were made over time. Four stages of recording, which were two days apart, were performed. The Cool Edit Pro 2.1 application was used to simultaneously record the signals from the 12 microphones and, in a later stage, to filter those signals using BPFs. Two BPFs, with different band-pass frequencies, were used to exclude most background noises: (1) BPF1, which uses Chebychev-1 and passes only frequencies between 3 and 5.5 kHz, and (2) BPF2, which

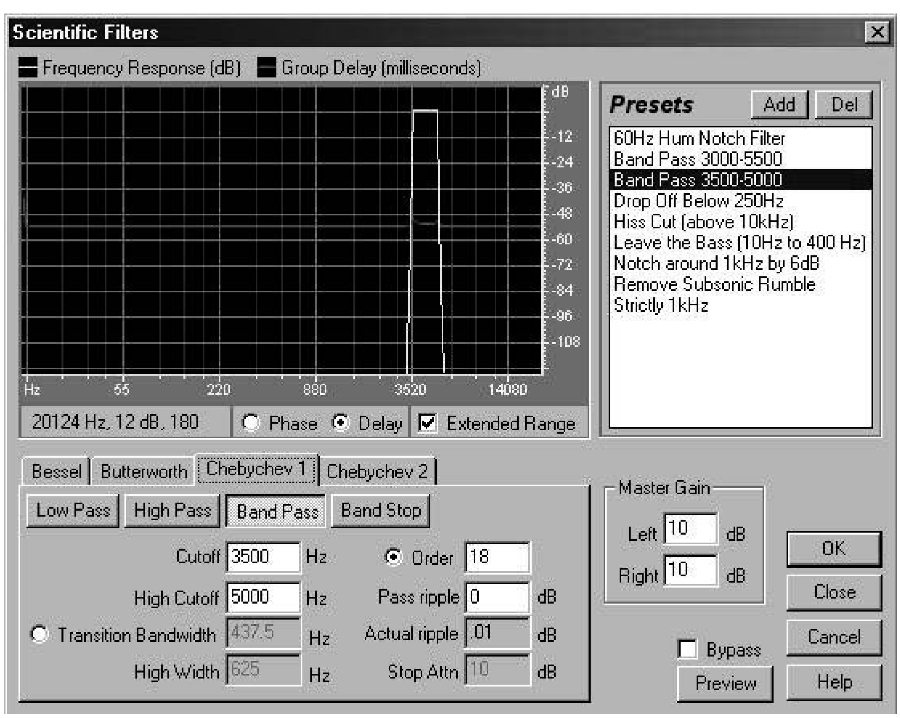

Figure 5.—Band-pass filter 2 (BPF2), which passes the 3.5- to 5-kHz frequency band designed by Cool Edit Pro 2.1.

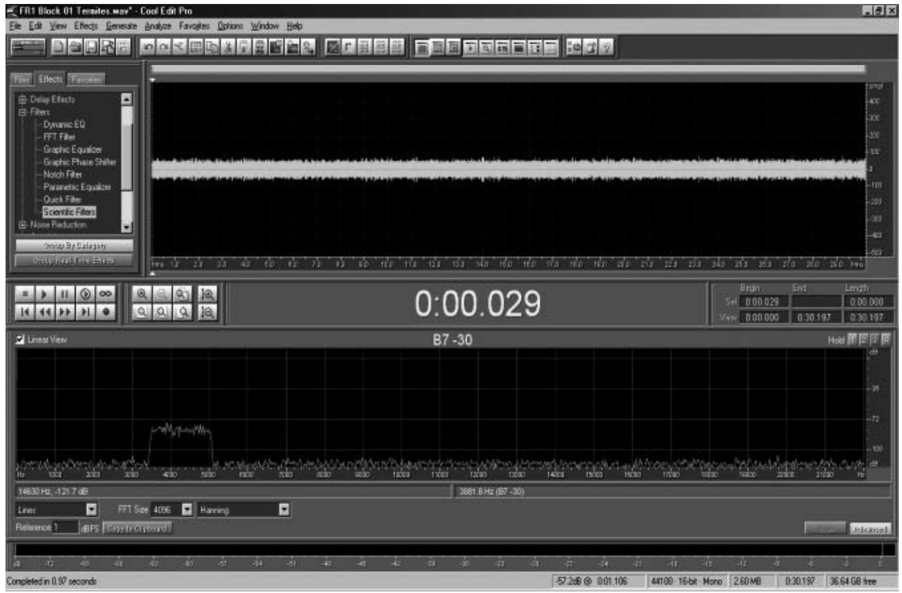

Figure 6.—Output signal after applying band-pass filter 1 (BPF1) displayed by Cool Edit Pro 2.1.

uses Chebychev-1 and passes an even narrower range of frequencies between 3.5 and 5 kHz. One termite treatment and one control treatment from the first replication of the experiment were chosen to determine a useful way to analyze the recordings. Figures 2 through 6 show the effect of applying BPF1 and BPF2 on the original input signal.

During the four recording stages, 10 replicates were conducted for all 12 microphone recordings (microphones 1

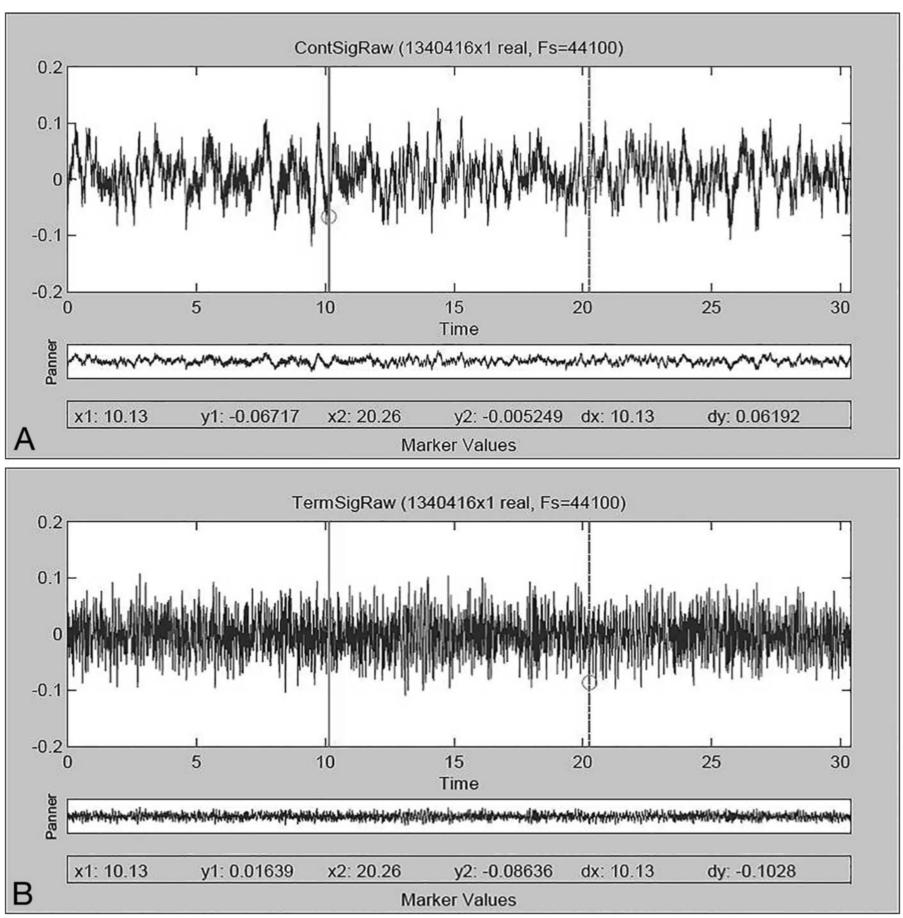

Figure 7.—Sound wave traces: (A) control sample and (B) sample exposed to termite activity.

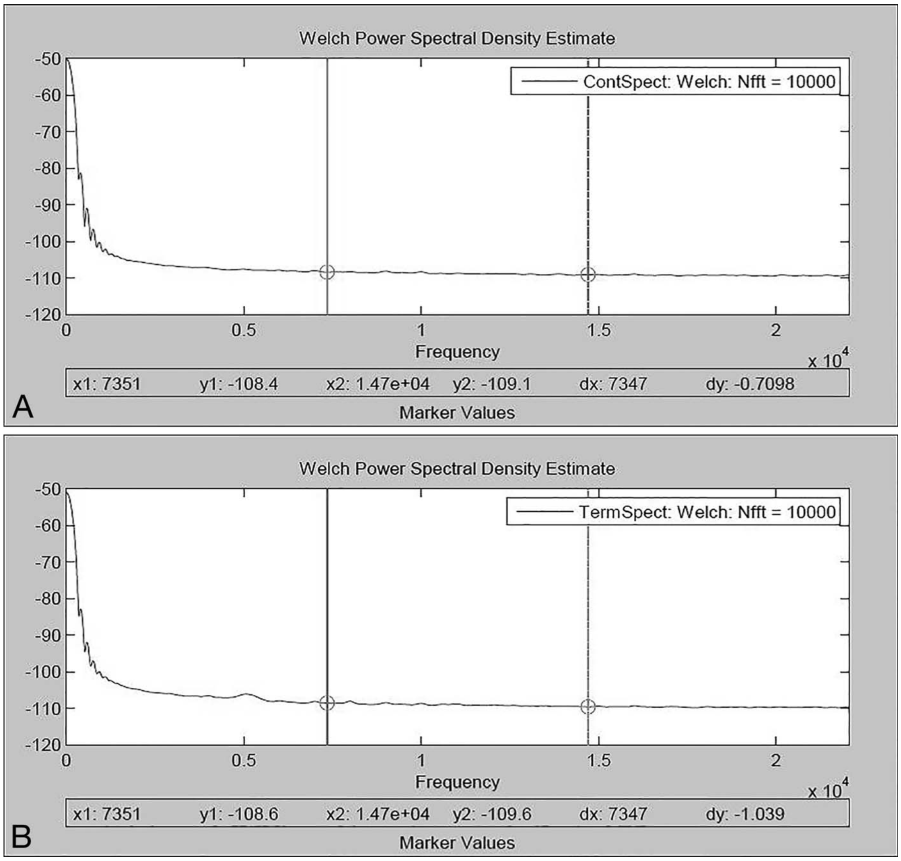

Figure 8.—Frequency spectra: (A) control sample and (B) sample exposed to termite activity.

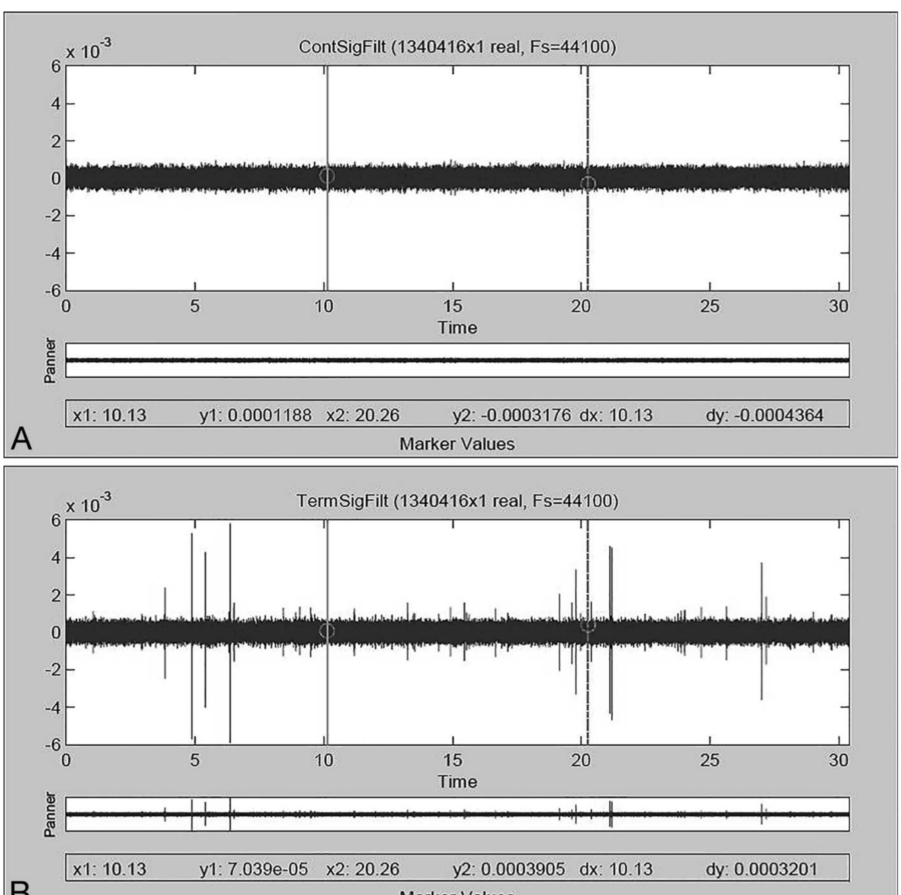

Figure 9.—Sound wave traces for the filtered recordings: (A) the control block and (B) the block exposed to termite activity.

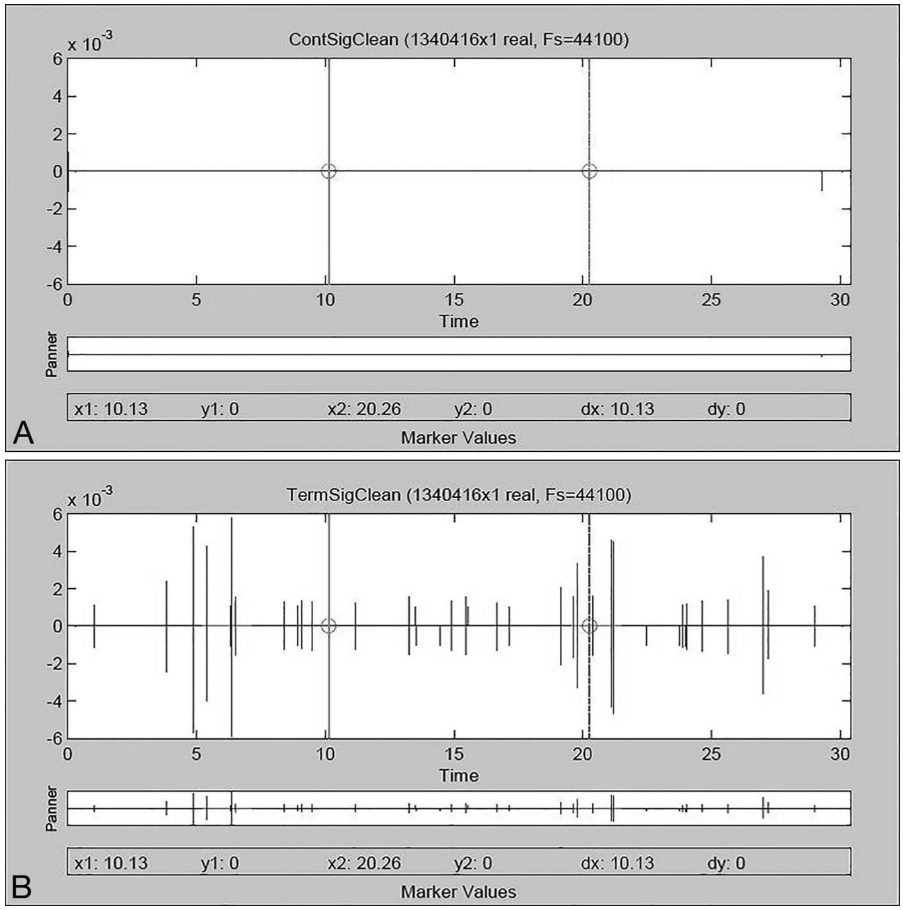

Figure 10.—Filtered sound recordings with the background threshold removed: (A) the control block and (B) the block exposed to termite activity.

to 6 were in a termite mound with termites, while microphones 7 to 12 were in a termite-free mound). A total of 480 recordings resulted. Half of the recordings (240) were from termite activities, and the others were used as controls. Using the Cool Edit Pro 2.1 application, BPF1 and BPF2 were set and applied to the recordings. The resultant signals were studied, and the number of AE events that were most likely related to termite activity in the wooden blocks was observed and manually noted. As this process depends on manual observation and counting of probable sounds due to termite activities, it was important to find a semi-automated technique for data filtering and counting.

Matlab software was used to automate the process. The raw recordings from the WAV files were imported into the Matlab software package for analysis. In most cases, ''sptool,'' one of the features of Matlab, was used to display and modify the data, allowing more consistent results to be achieved.

Results

While it was interesting to note the slight variations in sound wave traces, real differences due to termite activity are probably too subtle to be picked up by simple observation or listening. A comparison between the control sample and the sample exposed to termite infestation is presented in Figure 7.

Fourier analysis of the two signals, shown in Figure 8, revealed a slight peak in the frequency spectrum at about 5 kHz in the samples exposed to termite activity that is not present in the control sample. Based on this 5-kHz peak, a BPF was implemented in the Matlab's ''sptool'' to capture the signals around this peak in the control and termite data samples. The two signals are quite different from each other after filtering. The sound wave traces for the blocks that were exposed to termite activity had distinctive peaks that could be heard above the background noise, while the control trace did not. These are illustrated in Figure 9.

It is evident that the peaks in these filtered sounds extend above some fixed threshold of background noise, so the data were exported back to the Matlab work space and processed on an individual sample point basis to capture only those elements in the sound that extended above a predefined threshold level. The resulting data structure was imported back into ''sptool.'' The sound wave trace for the modified patterns is displayed in Figure 10.

When this final sound wave for the blocks exposed to termites was played through the speakers, the distinctive AE events associated with termite activity in the wood could be clearly heard without interference from other sounds. The only difference in the modified Matlab code is that the threshold value is slightly changed. The threshold value was varied to achieve the best output response for detecting termites.

Analysis of detected AE signals showed no termite activity in the control blocks, clearly distinct from the other termite block readings. A number of transformation techniques were tried, but none of them could normalize the data. Hence, Kruskal-Wallis analysis of variance, illustrated in Figure 11, was used to analyze the data, as the data were not normally distributed. Figure 12 shows a box plot of the final analysis and demonstrates that the average number of detected AE events in the termite-infested blocks was significantly higher than in the control blocks ($P < 0.05$).

Discussion

In this experiment, the sound signals were processed at different stages to facilitate data analysis. The multiple handling of the sound data could be an issue and could raise some result sensitivity concerns. Designing and implementing the two BPFs in the Cool Edit Pro 2.1 application (Chebychev-1 of band-pass frequencies between 3 and 5.5 kHz and Chebychev-1 of band-pass frequencies between 3.5 and 5 kHz) was helpful in removing most of the background noise frequencies, leaving the termite activity sound clearly detectable even by the human ear. This experiment, as illustrated in Figures 11 and 12, clearly shows the ability of Matlab tools to distinguish between termite-infested blocks and the control ones. This means that Matlab can be utilized as part of a future termite detection system or device.

This result was compared to RPW activity frequency range in palms, which was found to be around 2.25 kHz (Gutiérrez et al. 2010, Martin and Juliet 2013). Siriwardena et al. (2010) also used the 0.8- to 2.5-kHz pass range in a BPF to detect RPW activity. This experiment revealed that termite feeding pulses or AE event repetitions were in the range of 13 to 21 events per second. It is noteworthy here that Mankin (2013) found that insects usually produce 3- to 30-ms impulses of 0.2- to 5-kHz sound. Termite workers may provide more detectable sound through their feeding in the wood than soldier activities. Similarly, de la Rosa et al. (2008) concluded that peak activities at 2.6- and 6-kHz frequencies were detected due to termite AE events.

The blocks used in these experiments were small, and therefore the experiment did not account for signal attenuation or frequency dispersion as in the case of sound traveling through tree wood or wooden structures. Additionally, the termites were in an artificial environment (conditioned room temperature was set to 32°C, and relative humidity was set to 55%), and therefore their behavior may not have been like that in their natural environment. The above limitations must be considered when analyzing the results.

Conclusions

The wooden block experiment generated some important results. Termite activities can be clearly detected as acoustic signals in the 4.5- to 5-kHz range of frequencies. Furthermore, applications such as Matlab and Cool Edit Pro 2.1 may assist in filtering, analyzing, and even detecting termite activities in a future AE termite detection technique or device. Termite activities in the wood may be detected using AE recording. Some results from this experiment could assist in defining the termite AE signature to some extent by analyzing AE signals that were generated due to

Kruskal-Wallis ANOVA Table

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	97.786	1	97.7857	5.86	0.0155
Error	119.214	12	9.9345		
Total	217	13			

Column	Definition
source	The source of the variability.
SS	The sum of squares due to each source.
df	The degrees of freedom associated with each source.
MS	The mean squares for each source, which is the ratio SS/df.
Chi-sq	That is the chi-squared statistic.
Prob>Chi-sq	The probability that the deviation of the observed from that expected is due to chance alone

Figure 11.—Kruskal-Wallis analysis of variance.

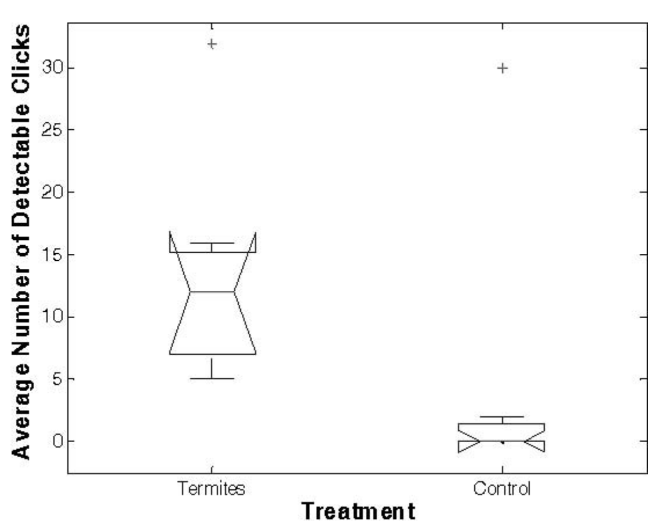

Figure 12.—The average numbers of detectable acoustic emission (AE) events in termite and control samples.

termite activities in the wood. It was clear that most of the detected termite AE events were in the frequency ranges between 4.5 and 5 kHz. A clean termite-related AE was extracted from the general AE emissions in the wooden blocks using Matlab tools.

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