A preliminary investigation of various signal phenomena generated by termite infestation

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Abstract. Subterranean termites are major urban pests in Indonesia and lead damage to wooden structures and buildings. Termite pest management involves two sections: prevention and control. The most crucial part of termite control is to detect termites; however, due to their cryptic behavior, the termite infestation evidence on wooden structures is difficult to detect visually. When termite infestation is active and wood damage is occurring, the distinction of various signal phenomena are released including moisture content, temperature and acoustic emission. The identification of these phenomena becomes the basic foundation for designing a future termite detection system. The aim of this study is to identify various signal phenomena generated by termite infestation. In this investigation, the pine wood, as the medium for termite infestation, was divided into two groups, i.e., the wood infested by 220 termites (‘infested’) and the normal wood as a control (‘uninfested’). Each signal phenomenon generated by termites was observed and analysed to produce six pieces of information, i.e., (a) moisture content; (b) temperature; (c) four information of acoustic emission such as energy, entropy, peak frequency and zero moment power. Based on statistical analysis of Duncan multiple range test (DMRT; two-way ANOVA, \( P \leq 0.05 \)), it was revealed that the information that can distinguish significantly between infested and uninfested wood are moisture content, temperature, energy, entropy and zero moment power. Finally, various phenomena (i.e., moisture content, temperature and acoustic emission) can be embedded and integrated in the sensing technology of termite detection.

Keywords: acoustic emission, signal phenomena, termite infestation, termite detection

1. Introduction
Termites are the most destructive and economically important insect pest of wooden structures, buildings and other cellulose products [1, 2]. Living in large underground colonies, termites may infest any wood in contact with the soil and may even construct protective shelter tubes over non-wood materials to attack wood above ground [3]. These social insects having a soldier, worker, queen and king caste, are widespread to terrestrial environment [4]; the main executors of various building damage are the termite worker and soldier (figure 1). Of the >3000 termites species recognised globally, 80 are known to cause serious damage, and the genus Coptotermes contains the largest number among these serious pest species [5, 6]. In Indonesia, the economic cost of termite damage to wood used in and around buildings is great. It is difficult to establish the exact amount of damage caused by termites, but estimates of yearly damage of IDR 8.68 trillion are common [7]. These numbers may not include the
cost of treatments (both preventive and curative), repairs to damage wooden structures and disadvantage of property value. To overcome termite attacks and avoid a higher wood damage, a non-destructive technique is required that can detect a termite infestation in wood as early as possible [8].

![Termites](image)

**Figure 1.** Colony structure of genus *Coptotermes* (a) worker, (b) soldier (this image provided by Lenhard, 2007 [9]). The quantity of individuals of each caste varies among species and also depends on the age and size of the colony.

Detecting termites are difficult. All termite species, be they drywood, dampwood or subterranean, are cryptic, because this is their primary defensive strategy against predation. Detecting infestations in structures and locating the entrance routes used by termites are often critical in effective management of pests. Various detection methods are used, with some varying for different types of termites. Basically, the termite detection system is now usually combined with the use of more sophisticated instruments, such as borescopes, moisture meters, electronic odor devices, acoustic emission and infrared heat detection; in addition, dogs have been trained to smell termites [10]. Recently, acoustic emission is a technique used to detect termites. When termite infestation is active and wood damage is occurring, microfractures are generated in the wood by the feeding of workers. As a result, elastic waves, or an acoustic emission phenomenon are generated, owing to the release of the strain energy stored in the wood [11]. In addition, other signal phenomena that occur due to termite infestation are moisture content and temperature. Clearly, there is a scope for improvement in termite detection, i.e., through a combination of various phenomena. In this study, considerable attention has been given to identify the characteristics of these phenomena including moisture content, temperature and acoustic emission. The results of this study become the basic foundation for designing a future termite detection system.

## 2. Materials and method

### 2.1. Timber Test

In this paper, for experimental design protocol, is provided by Nanda et al. [5, 8]. Firstly, Pine wood, used as a medium for the feeding activity test of termites *Coptotermes curvignathus*. This wood has a size of 20 (l) x 9.5 (w) x 2.5 (h) cm and the inside has a hole with size 12 (l) x 6 (w) x 0.5 (h). Furthermore, we divide the wood into two classes, i.e., the wood infested by 220 termites *C. curvignathus* (‘infested’) and the normal wood that is not infested by termites (‘uninfested’). Each class consists of five wood samples. In addition, the termite infestation is carried out for two weeks.

### 2.2. Various Signal Phenomena

After the termite infestation process for two weeks, the characteristic phenomena in each class were acquired. The three signal phenomena revealed in this investigation are as follows: (1) Firstly, moisture content signal. It was measured by wood moisture meter GMK 1010 model (G-won Hitech CO., Ltd. of
Korea). Average moisture content can be expressed by Equation (1), where \( m_i \) is moisture content value on the wood surface at a point \( i = 1, 2, 3, \ldots, n \).

\[
\hat{m} = \frac{1}{n} \sum_{i=1}^{n} m_i
\]  

(1)

(2) Secondly, the temperature signal. This signal was measured using thermometer infrared (Fluke 62 Max, Washington, USA). The mean temperature is calculated using Equation (2), where \( T_i \) is the temperature value on the wood surface at a point \( i = 1, 2, 3, \ldots, n \).

\[
\hat{T} = \frac{1}{n} \sum_{i=1}^{n} T_i
\]  

(2)

Furthermore, to provide visualisation of the contouring of moisture content and temperature on the wood surface, then both are plotted using the Surfer software® 13 (13.0.383 64-bit). This contouring is performed under the kriging method with easy built-in function [12], where every moisture content and temperature at each point is used as input. In a brief description [13], the kriging method is a linear interpolator that belongs to the best linear unbiased estimator (BLUE) family estimators. Thus, the primary purpose of the kriging method is to estimate a certain unknown variable as a linear combination of the known values. As in optimal interpolation, kriging requires that the observed process is second-order stationary, which means that the means values and the standard deviation have to be independent of the location.

(3) The last signal, acoustic emission. The equipment used for the acoustic signal data acquisition is electret microphone sensor by ITEad Studio, with a sensitivity of -56 dB (frequency of 0.1-10 kHz), which is connected to the microcontroller. This signal produces four informational pieces, i.e., energy, entropy, peak frequency and zero moment power. The energy \( E \) and entropy \( H \) can be calculated following Equations 3 and 4, respectively [3, 14, 15]. Where, \( E_i \) is energy, \( H \) is entropy, \( W_L \) is length of the frame size, \( \sigma_j \) is the energy ratio of sub-frames with the total energy total and \( X_i \) is value of signal, \( n = 1, \ldots, W_L \).

\[
E = \frac{1}{W_L} \sum_{n=1}^{W_L} |X_i|^{2}
\]  

(3)

\[
H = -\sum_{n=1}^{W_L} \left( \frac{1}{W_L} \right) \log_2 \left( \frac{1}{W_L} \right) X_i
\]  

(4)

Unlike energy and entropy, which can be directly generated in the time domain, the peak frequency and zero moment power require the signal transformation first due to both parameters being in the frequency domain. One well-known method used for signal transformation is fast fourier transform. In this study, FFT was applied to produce peak frequency and zero moment power. The peak frequency \( (P_f) \) is determined based on the maximum peak of the overall signal length, whereas zero moment power \( (M_0) \) is defined as the area under the peak of magnitude. This can be computed using Equation 5 [8], where \( W_f \) is frequency length \( (n = 1, \ldots, W_f) \), \( P(n) \) = magnitude and \( P_{(n)} \text{max} \) = maximum value of the magnitude.

\[
M_0 = \sum_{n=1}^{W_f} \frac{P(n)}{P_{(n)} \text{max}}
\]  

(5)

2.3. Statistical Analysis

Statistical significance of the difference between infested and uninfested class was determined using the analysis of variance (two-way ANOVA, \( P \leq 0.05 \)) and comparison was done by Duncan multiple range test (DMRT 95%). All data were analysed using the XL-stat software © Addinsoft 1995-2014.
3. Results and discussion

3.1. Moisture Content Signal

Figure 2, shows the contouring of moisture content on wood surface attacked by termites and normal wood. Visually, the infested wood has a higher moisture content than normal wood, i.e., maximum moisture contents for infested and uninfested wood is 12.9% and 11%, respectively. In infested wood, we considered that areas that have maximum moisture content indicate the center of termite attack inside the wood. An important consideration is the termites’ dependency on moisture. Subterranean termites seek out moisture for survival [16]. Their high moisture requirements increase the likelihood that they will maintain contact with the soil or locate near areas where water collects, i.e., leaking pipes can keep wood and soil continually damp and create a perfect home for termites. Thus, it is not surprising that wood attacked by termites has a higher level of moisture than normal wood. They extract water from the wood on which they feed, and also produce water internally during the digestive process. They prefer wood with 12.01 ± 0.753% moisture content.

![Figure 2](image-url)  
**Figure 2.** The contouring of moisture content on the wood surface by kriging method, (a) infested wood; (b) uninfested wood.

![Figure 3](image-url)  
**Figure 3.** The contouring of temperature on the wood surface by kriging method, (a) infested board; (b) uninfested board.
3.2. Temperature signal
Figure 3, shows the contouring of temperature on wood surface attacked by termites and normal wood. Visually, the infested wood has a warmer temperature than the normal wood, i.e., maximum temperatures for infested and uninfested wood are 26.1 °C and 25.89 °C, respectively. In infested wood, we considered that areas that have maximum temperature indicate the center of termite attack inside the wood. According to Indrayani et al. [11], termites obtained their favorable temperature conditions indirectly via the available moisture from wood and metabolic process. As a result of termite attacks, the infested wood has a warmer temperature than the normal wood.

3.3. Acoustic emission signal
Figure 4, describes the acoustic emission signal in the infested and uninfested class on the frequency domain. Visually, the infested wood has a higher magnitude than uninfested wood. This is due to the activity of termites that produce acoustic signals; for instance, when termites are feeding and moving in the wood, they generate acoustic signals. In addition, acoustic signals can also be produced by termites as alarm signals through head banging to the wood [17]. Hence, in the last decade, the acoustic emission phenomenon becomes a foundation for designing a termite detection tools by various researchers worldwide [5, 18-21].

3.4. Evaluation
Understanding the various signal phenomena and conditions that favour termite activities better prepares one to develop a termite detection system. Each signal phenomenon generated by termites was observed and analysed to produce six pieces of information, i.e., (a) moisture content; (b) temperature; (c) four pieces of information of acoustic emission such as energy, entropy, peak frequency and zero moment power. Characteristics of various signal phenomena generated by termite infestation are provided in Table 1.

A statistical analysis of Duncan multiple range test (DMRT; two-way ANOVA, $P \leq 0.05$), revealed that the information that can distinguish significantly between infested and uninfested wood are $C$, $R$, $E$, $H$ and $M_0$. While for information $F$, peak of frequency, is not able to distinguish significantly between infested and uninfested wood due to the standard deviation value being very wide. Finally, various phenomena (i.e., moisture content, temperature and acoustic emission) can be embedded and integrated in the sensing technology of termite detection. However, it needs to be reaffirmed that the availability of a transducer in the market, which is able to sense the moisture content, temperature and
acoustic emission, needs to be investigated further. In addition, the transducer must be able to be integrated with each other to provide quick and accurate decisions, and it becomes a future research direction.

Table 1. Characteristics of various signal phenomena generated by termite infestation.

| No. | Signal phenomena | Information          | Wood condition |
|-----|------------------|----------------------|----------------|
|     |                  |                      | Infested       | Uninfested     |
| 1   | Moisture content (%) | 12.01 ± 0.753<sup>a</sup> | 10.49 ± 0.589<sup>b</sup> |
| 2   | Temperature (°C)   | 26.23 ± 0.205<sup>a</sup> | 25.68 ± 0.146<sup>b</sup> |
| 3   | Acoustic emission  | E 0.99926 ± 0.00034<sup>a</sup> | 0.99850 ± 0.00043<sup>b</sup> |
|     |                  | H -0.30062 ± 0.00034<sup>a</sup> | -0.30002 ± 0.00024<sup>b</sup> |
|     |                  | P<sub>1</sub> 642.964 ± 477.372<sup>ns</sup> | 398.378 ± 451.021<sup>ns</sup> |
|     |                  | M<sub>1</sub> 6.65733 ± 3.112<sup>a</sup> | 5.34948 ± 2.258<sup>b</sup> |

Different notation on the same row indicated significant value, DMRT 95% (P<0.05).

ns = not significant.

4. Conclusion

This work has successfully investigated various signal phenomena generated by termite infestation including moisture content, temperature and acoustic emission signal. Each signal phenomenon generated by termites was observed and analysed to produce six pieces of information, i.e., (a) moisture content; (b) temperature; (c) four information of acoustic emission such as energy, entropy, peak frequency and zero moment power. Statistical analysis revealed that the information that can distinguish significantly between infested and uninfested wood are moisture content, temperature, energy, entropy and zero moment power. Finally, various phenomena (i.e., moisture content, temperature and acoustic emission) can be embedded and integrated into the sensing technology of termite detection.

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