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Overhead line wooden pole condition sensing by acoustic method

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Abstract

The paper presents the design of a sensing system for non-destructive inspection of the health condition of wooden poles for overhead power lines. Acoustic impulse responses are collected for the analysis of the condition of different wooden poles. The concept of cumulative energy spectrum for feature extraction is introduced. Fuzzy logic is also used to solve the problem of small samples. Experimental results and the accuracy of the method are also presented.

Keywords: Wooden pole condition sensing system; Acoustic method; Cumulative energy spectrum; Fuzzy logic

1. Introduction

Wooden poles have been used to support telephone and electric lines for over a century. They may be attacked by insects such as termites, ants, or beetles. Termites work within wood and there is virtually no external evidence of their presence until the wood has fallen down. In the past, utilities installed poles with little thought to the necessity of regular maintenance. The need to minimize potential liabilities while maximizing the investment in wooden poles has encouraged many utilities to conduct regular inspection. In most cases, non-destructive inspection techniques are preferred. Non-destructive inspection is defined [1] as the technical method to examine materials or components in ways that do not impair future usefulness and serviceability. Various technologies, such as radiographic methods [2,3], static bending techniques [4], dynamic methods [5], acoustic emission techniques [6,7], and acousto-ultrasonic techniques [7,8] have been studied. Each of these techniques has both advantages and disadvantages with regard to cost, speed, accuracy, and safety. The desire for non-destructive inspection techniques that do not cause wood damage has stimulated the development of acoustic inspection techniques. In principle, a sound wave moving across a wooden pole is affected by all characteristics of the material, including growth rings, moisture, decay pockets, and a myriad of other wood properties [9]. The existing practice in local utility is based on experienced inspectors using a hammer as an effective tool for exciting wooden poles to detect internal decay. Usually, a lightweight hammer which is comfortable to swing and strong enough to stand repeated solid blows to the pole is used. A sharp pitch normally indicates the condition of the wooden pole is good, whereas a hollow sound or dull sound indicates that it is rotten. Suspicious areas will be drilled or cored with an increment borer and static bending technique may also be used to detect the condition of the wooden pole. However, the assessment is subjective and may vary from different workers. It is difficult for the workers to quantify as which pitch sound they should avoid and where is the borderline between good and bad. This paper presents the methodology of pole condition monitoring sensing system based on impulse responses using microcontrollers. Moreover, fuzzy logic method is also introduced to handle imprecise inputs and deal with non-linearity. Fuzzy logic systems have been successfully applied to many complex industrial processes and domestic appliances in recent years [10–12]. Unlike conventional approaches, no rigorous mathematical model is required to design a good fuzzy logic system. In many cases it can be implemented more easily such as using low cost 8-bit microcontrollers [13,14]. Experimental results and the accuracy of the method are also presented to demonstrate the effectiveness of the proposed fuzzy logic system.

2. Background theory

The condition of a wooden pole depends on the internal structure of the pole. If the pole is solid with very small cavities, the

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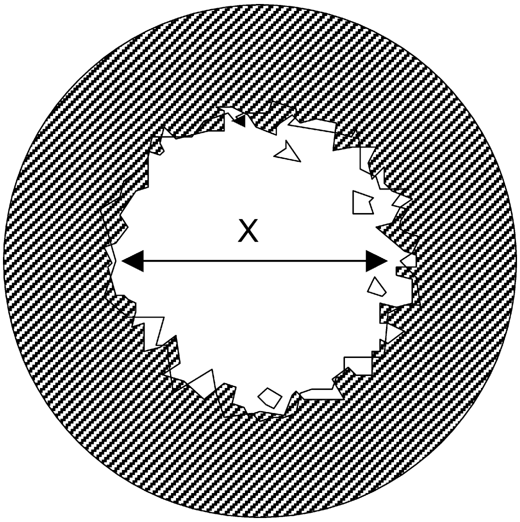

Fig. 1. Cross sectional view of a wooden pole with cavity.

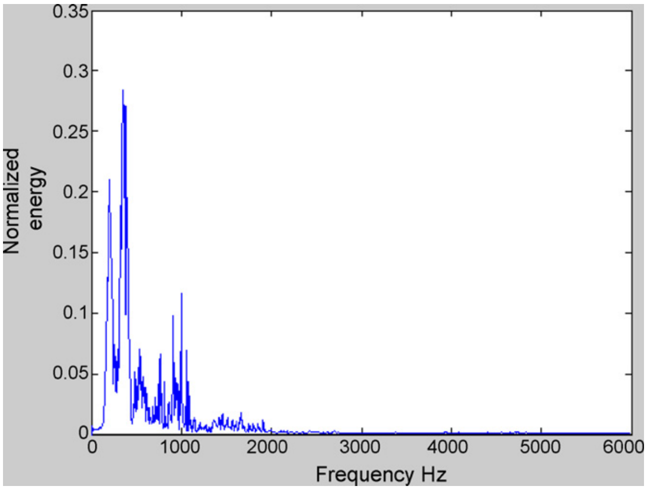

Fig. 3. A sample energy spectrum from a wooden pole.

condition is good. If cavities start to build up, the condition of the pole start to deteriorate. The larger the cavity, the poorer the condition of the pole becomes.

Fig. 1 shows a cross sectional view of a wooden pole with a large cavity. If there is an impact on the wooden pole, the wavelength of the sound produced will be proportional to the size of the cavity X. The larger the cavity, the longer the wavelength will be. The frequency of the sound f produced will therefore be inversely proportional to the size of the cavity.

$$f \propto \frac{1}{X} \tag{1}$$

Since the cavity will not be a perfect circle, the sound produced will spread around a centre frequency f_0 as shown in Fig. 2a instead of a clear pitch sound. Fig. 2b shows the frequency spectra of sound produced with large and small cavities.

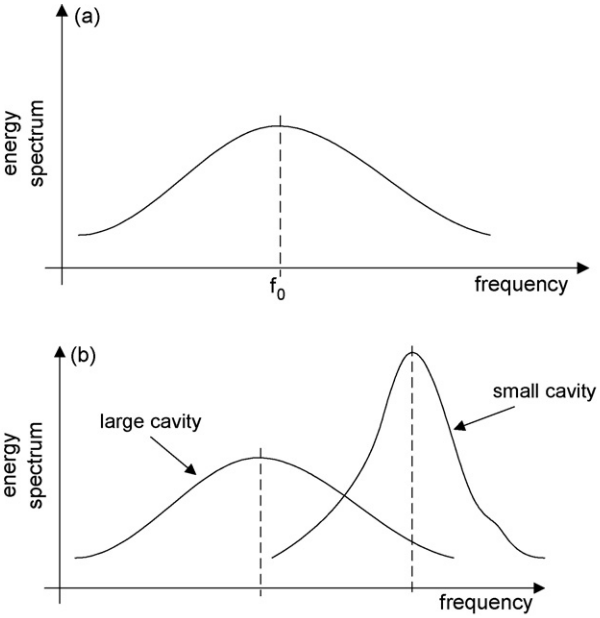

Fig. 2. Frequency spectra of sound wave generated from different size of cavities.

If the cavity is larger, the centre frequency will appear at a lower frequency (i.e. more energy will appear at the low frequency end). Apart from the sound generated by the cavity, there will be a mixed of sound produced by the pole itself and its attachment. Fig. 3 shows a sample of the energy spectrum obtained from a poor conditioned wooden pole. The energy spectrum obtained is very much different from the spectrum suggested in Fig. 2. Hence the direct assessment of the location of the pitch may give erroneous results. One way to get around the problem is to detect the existence of low frequency sound. If the relative frequency content of a wooden pole at low frequency range is over a certain threshold, which indicates a large cavity, this indicates the condition of the wooden pole is poor and vice versa.

3. Methodology

3.1. Frequency transformation

In order to detect the frequency content of the sound signal, impulse response of the sound signal is first sampled to give $x(k)$, $k = 0, 1, 2, \ldots, N-1$ where N is the number of data records collected. The frequency content of the signal can be obtained by taking Discrete Fourier Transform [15] to give

$$X(n) = \sum_{k=0}^{N-1} x(k)\,\mathrm{e}^{-j2\pi kn/N}, \quad n = 0, 1, 2, \ldots, N-1 \tag{2}$$

and the normalized energy spectrum is given by

$$S_{\mathrm{e}}(n) = \frac{1}{N}|X(n)|^2, \quad n = 0, 1, 2, \ldots, N-1 \tag{3}$$

The collected data may be corrupted by human errors, external disturbances and noise. In order to reduce their effects on the final spectral estimates, instead of taking one impulse response, M impulse responses are taken in order to average out the external disturbances. The smoothed normalized energy is thus given