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A study of acoustical characteristics of pine nut based on a fractal dimension method*

LI Jian-ping[†1], WEI Bao-gang[2]

([1]*School of Biosystem Engineering and Food Science, Zhejiang University, Hangzhou 310029, China*)
([2]*School of Computer Science and Technology, Zhejiang University, Hangzhou 310027, China*)
[†]E-mail: jpli@zju.edu.cn

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Abstract: The structure difference of pine nuts was tested on the basis of their acoustical characteristics in order to distinguish whether they were open or closed. In this experimental study, pine nuts were dropped from a certain height onto a ceramic board; the impinging sound was recorded by a microphone. The sound wave graph and frequency spectrum graph were obtained while the impinging sound was analyzed by computer. Fractal dimension was calculated on sound wave graph and frequency spectrum graph of open and closed pine nuts. The result of test and analysis showed that the sound wave fractal dimension of open pine nuts was smaller than that of closed ones. The frequency spectrum fractal dimension of open pine nuts was larger than that of closed pine nuts. Fractal dimension of sound wave and frequency spectrum could be used as important indices to distinguish whether the pine nut was open or not.

Key words: Pine nut, Acoustical characteristic, Frequency spectrum, Fractal
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INTRODUCTION

Pine nut is a kind of nut consumed much in people's daily life. Closed pine nuts are not good for customers because it is difficult to be manually opened, so pine nut products containing closed ones are considered as low quality with low commercial values. Manual separation of closed and open pine nuts is very labor and time consuming. It is important to develop a type of machine to automatically separate the closed pine nuts from the products. The acoustical characteristics of open and closed pine nuts may be useful for the separation purpose. Acoustical characteristics of agricultural product have been used for its quality measuring and grading (Brusewitz and Venable, 1987; Sugiyama *et al*., 1994). Pearson (2001) applied acoustical method to distinguish whether a pistachio nut was open or closed. Their test result showed that the sound wave and frequency spectrum were quite different between open and closed nut. The sound wave of open nut had longer duration than that of closed nut and there was a peak near the 7000 Hz frequency spectrum.

The evaluation of acoustical characteristics is a kind of signal analysis. There are many methods of signal analysis, such as frequency spectrum analysis which is based on different dominant frequency for the purpose of judgment and analysis (Shmulevich, 1996; Wang and Teng, 2004). The dominant frequency is generated at the point of maximum peak in a frequency spectrum graph of a type of experimental signal. Determination of mass center of frequency spectrum graph is another signal analysis method used by many scientists (Cho *et al*., 2000). Some other ways such as energy ratio and slope of frequency spectrum graph are not very effective when the dominant frequency does not fully reflect the

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inner characteristics of the signal. In this case, it is necessary to find more other eigenvalues.

Fractal theory was created by a French mathematician, Mandelbrot in the mid of 1970's (Zhang, 1995). In the recent two decades, fractal theory has become a new mathematical tool applied in many fields such as physics, chemistry, geography, medicine and computer science. Fractal theory can be used to analyze universal, irregular and random phenomena in nature. Fractal dimension is a key eigenvalue in fractal analysis.

This study was aimed at evaluating acoustical characteristics of open and closed nuts using fractal analysis, and to find the difference of the fractal dimensions of sound wave and frequency spectrum between open and closed pine nuts.

MATERIALS AND METHODS

Acoustical measurement system

Fig.1 is a schematic diagram of the measurement system used in this study. The system was composed of computer, microphone, dropping board and impacting board. Each test pine nut was dropped gravitatively from a dropping board at certain height (75 mm) and its sound was recordeded by microphone. The sound signal was immediately analyzed by software (Adobe Audition 1.5) as soon as it was received by the computer. After this analysis, a sound wave graph was obtained for each test, which was then further analyzed for plotting its frequency spectrum diagram. Ceramic was used as impacting board in order to reduce greatly the vibration of the impacting board and ensure the sound was caused by pine nuts only rather than by bumping.

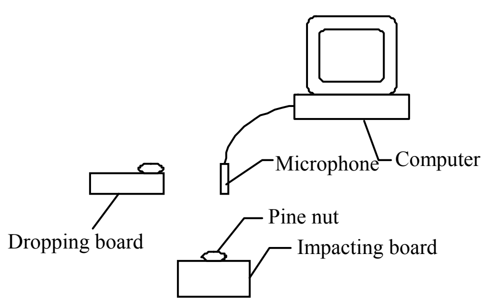

Fig.1 Schematic diagram of experiment and analysis system

Test materials and methods

Drying pine nuts brought from supermarket were used as experiment materials. Acoustical characteristics were tested according to pine nut size and whether it was opened or closed. There were 500 pine nut samples used, with repeating 5 times for each time the number of open pine nuts and closed pine nuts was equal. During the test, each pine nut was maintained in horizontal posture when it dropped and contacted to the impacting board. The vertical height from dropping board to impacting board was 75 mm and the vertical distance between microphone and impacting board was 75 mm.

EXPERIMENTAL DATA AND ANALYSIS

Time domain characteristics of acoustical signal of open and closed pine nuts

Fig.2 shows the sound wave graphs of open and closed pine nuts, respectively. For convenience in analysis and comparison, the sound wave value was normalized so that the maximum amplitude became 1. As indicated in Fig.2a, open pine nuts had long duration time and the curve dropped slowly after reaching the highest point. Fig.2b shows that the duration time of closed pine nuts was quite short, and that the curve fell quickly after reaching its maximum peak.

Frequency spectrum characteristics of open and closed pine nuts

Figs.3 and 4 present the graphs of sound wave and frequency spectrum of open and closed pine nuts. There was an energy peak of open pine nuts from 3500 Hz to 7000 Hz with its maximum amplitude value occurring near 6000 Hz. There was a minimum amplitude value approximately at 8000 Hz on both open and closed pint nuts. The amplitude value of open pine nuts was smaller from 8000 Hz to 15000 Hz. However, the amplitude value area on both sides of 8000 Hz was basically the same and even on closed pine nuts.

FRACTAL DIMENSION CALCULATION OF ACOUSTICAL SIGNAL ON PINE NUTS

Method of calculating fractal dimension

Fractal dimension represents complex status of

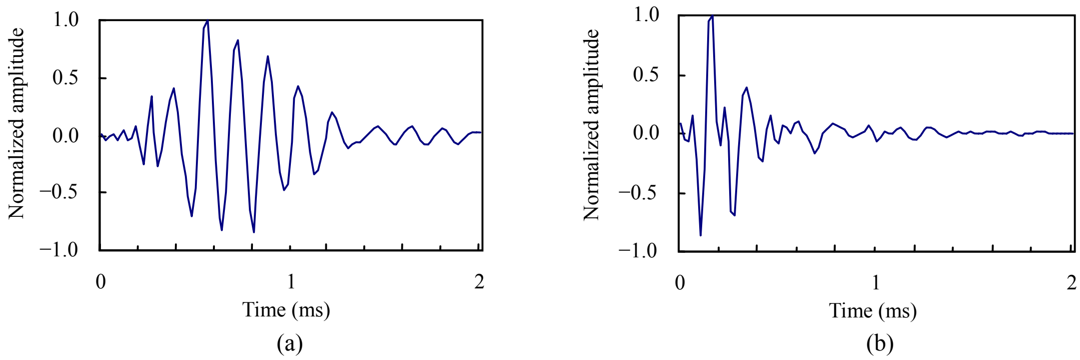

Fig.2 Typical time domain signal. (a) Open pine nut; (b) Closed pine nut

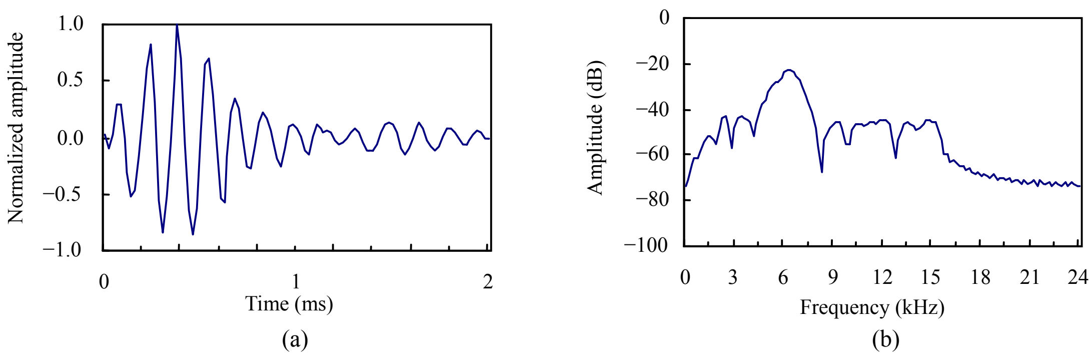

Fig.3 Typical signal of open pine nut. (a) Time domain; (b) Frequency domain

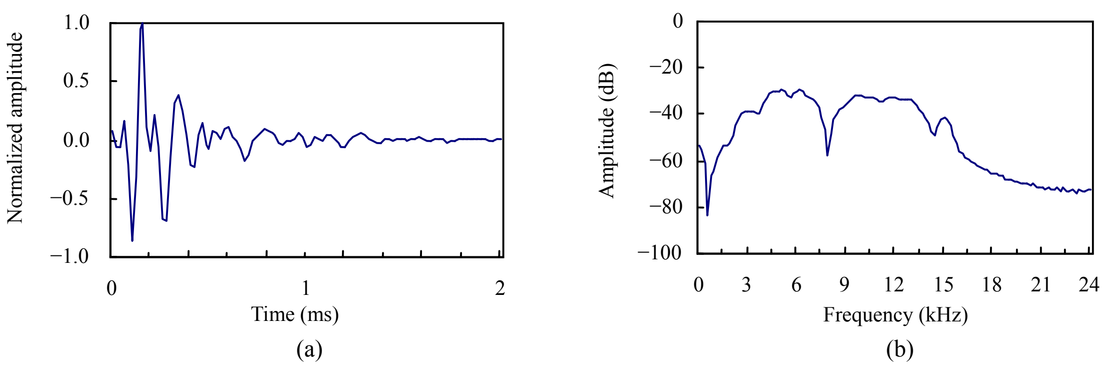

Fig.4 Typical signal of closed pine nut. (a) Time domain; (b) Frequency domain

described objects. Different objects have different ways of fractal calculation and each method has its own suitable range. The research target of fractal dimension is irregular and self-similar. As a form index, fractal dimension indicates the degree of irregularity. The Higuchi (1988)'s method can be applied to calculate fractal dimension in time series whose fractal model was self-similar in all dimension scale. According to a given time series array $X(i)$ (i=1, 2, …, N), a new time series can be structured as follows:

$$X_\tau^m : X(m), X(m+\tau), X(m+2\tau), \ldots, X\{m+[(N-m)/\tau]\tau\}; \quad m=1, \ldots, \tau, \tag{1}$$

where, $[x]$ is Gauss notation which represents the integer part of x.

The curve length can be calculated by the following formula:

$$L_m(\tau)=\left\{\left(\sum_{i=1}^{[(N-m)/\tau]}\left|X(m+i\tau)-X(m+(i-1)\tau)\right|\right)\cdot\frac{N-1}{[(N-m)/\tau]\tau}\right\}\frac{1}{\tau}, \tag{2}$$

where, $(N-1)/\{[(N-m)/\tau]\tau\}$ is a normalization coefficient of a curve.

Assume that $L(\tau)$ is the whole curve length, while τ is the curve's measured interval distance, and that the length of $L(\tau)$ depends on τ. With the increase of the degree of irregularity, the length of $L(\tau)$ increases. From the curve's statistical self-similarity, the following formula can be obtained:

$$L(\tau)\propto\tau^{-D}. \tag{3}$$

From the Higuchi method put forward, with following formulas:

$$D=-\log L(\tau)/\log\tau, \tag{4}$$

$$L(\tau)=(1/\tau)\sum_{m=1}^{\tau}L_m(\tau), \tag{5}$$

a logarithmic plot was made with $\log L(\tau)$ as vertical coordinate and $\log(\tau)$ as horizontal coordinate. Least squares fit of some points in the logarithmic plot yielded a straight line. After calculating the slope rate and negative value, we finally got the curve's fractal dimension D. Fractal dimension should be 1.0 to 2.0 because the curve is displayed in two dimension plane. Fractal dimension increases when the curve becomes more complicated. Fractal dimension D becomes large as the signal becomes irregular. So fractal dimension can be seen as a quantization index to judge whether the signal is irregular or not. Fig.3b indicates that the frequency spectrum of open pine nut was more irregular from 750 Hz to 15000 Hz. Fig.4b shows that the frequency spectrum of closed pine nuts was flat. A fractal dimension threshold could be found through extensive test to distinguish the open and closed status of pine nuts. When the test value was larger than threshold, it was an open pine nut. Otherwise it was a closed pine nut.

Fractal dimension calculation of acoustical characteristics of pine nuts

Fractal dimension of sound wave and frequency spectrum of pine nuts with open and closed shell can be calculated by Eq.(2) and Eq.(5). Time span in sound wave graph of open and closed pine nuts was set to be same in order to ensure the same array length. Frequency spectrum ranged from 750 Hz to 15000 Hz. Open pine nut and closed pine nut had obvious difference in frequency spectrum during this span. So it was easy to compare each other. Table 1 was obtained by calculating fractal dimension of sound wave signal and frequency spectrum curve. Table 1 contained some typical fractal dimension after the processing of large volume of data. The fractal dimension of open pine nut wave signal was smaller than that of closed pine nut. The mean value of open pine nut was fractal dimension D=1.4097, and that of the closed pine nut was fractal dimension D=1.6576. The fractal dimension of frequency spectrum of open pine nut was larger than that of closed pine nut. The average value of the former was fractal dimension D=1.3497, the latter was fractal dimension D=1.1846. Fig.2 shows that fractal dimension had relationship with the irregularity of the curve analyzed. The fact that fractal dimension becomes larger indicates the curve would be more irregular.

Table 1 Fractal dimensions of pine nut with open and closed shell on time and frequency domain

No.	Status of pine nut	Fractal dimension	
		Sound wave	Frequency spectrum
1	Open	1.3854	1.3650
2	Open	1.4582	1.3934
3	Open	1.4800	1.3004
4	Open	1.3005	1.3064
5	Open	1.4244	1.3835
6	Closed	1.7651	1.2150
7	Closed	1.6230	1.1458
8	Closed	1.6160	1.2112
9	Closed	1.6488	1.1869
10	Closed	1.6350	1.1643

CONCLUSION

Sound wave graph and frequency spectrum graph of pine nut with open and closed shell were obtained from the above test. After analyzing the sound wave graph and frequency spectrum and calculating the fractal dimension, the main results of this research were summarized as follows:

(1) The energy in open pine nut frequency spectrum mainly concentrates at 3500 Hz to 7000 Hz. The frequency spectrum of open pine nut has obvious protruding peak, while the frequency spectrum graph of closed pine nut was flat.

(2) The duration time of open pine nut sound wave was longer than that of closed pine nut.

(3) The sound wave curve of open pine nut was relatively regular during analyzing its curve on a given length of sample time. However, the sound wave curve of closed pine nut on a given sample time was more irregular and had obvious mutation. From the viewpoint of frequency spectrum curve, especially from 750 Hz to 15000 Hz, the open pine nut was irregular and the closed pine nut was regular.

(4) The fractal dimension of open pine nut sound wave was smaller than that of closed pine nut, while the fractal dimension of frequency spectrum of open pine nut was larger than that of closed pine nut.

(5) Fractal dimension of sound wave curve and frequency spectrum curve can be used as an index to judge whether the pine nut is open or closed.

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