Hammering Test with Image and Sound Signal Processing

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Abstract

A method for discriminating a property of an object with the use of generated sound when striking it with a hammer is called a hammering test. This method, however, depends on human experience and skills. In addition, if we perform this test over a wide area of object, it is required to manually record hammering positions one by one. In order to solve these problems, this paper proposes a hammering test system consisting of a computer and a video camera, through which image and sound signals of a hammering scene are acquired. As a basic study, we inspect thickness distribution over a wood board, where thickness is estimated by sound signal processing in time and frequency domains, and each hammering position is determined by image signal processing. A preliminary experiment showed the validity of the proposed method.

1 Introduction

By striking an object and hearing generated sound, humans can recognize the difference in thickness, the quality of materials, or the existence of defects. An inspecting method using the generated sound when we strike an object with a hammer is called a hammering test method. It has an advantage that it performs non-destructive and simple investigation. On the other hand, it has a disadvantage that it lacks objectivity because it depends on individual experience and skills. In order to solve this problem, it is necessary to analyze the hammering sound numerically by computer. As an example of such research, there is a study on inspection of concrete cracks [1][2][3]. A method using ultrasonic waves is employed to detect the depth of cracks [4][5].

In this paper, we propose a hammering test system, which investigates the thickness distribution of a wood board and is simply realized with a video camera and a personal computer. A scene of object hammering is taken by a video camera. Captured sound signals are analyzed to distinguish the thickness of each portion of the board. Each hammering position is determined by processing of image signals simultaneously. Finally, the system gives the hammering test result graphically, with a two-dimensional thickness map.

2 Procedures

The procedure flow of the proposed hammering test method is shown in Fig.1. This section explains these five procedures.

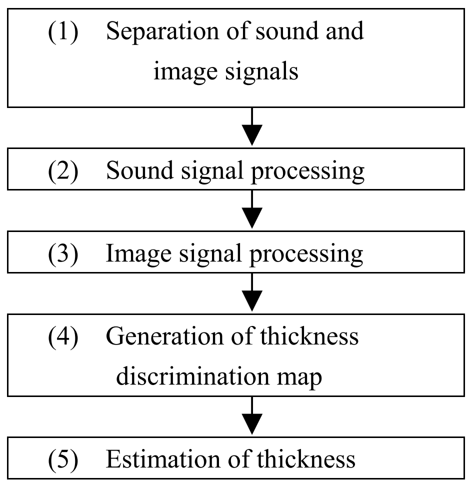


Fig.1 Procedure flow.

2.1 Separation of sound and image signals

Since the captured signals are a complex of sound and image signals, we should divide the signals into two signal sets. Separation is realized by reading the signals structure unit by unit sequentially, and contiguous sound signals and contiguous image signals are composed, respectively.

2.2 Sound signal processing

The sound signals are examined both in time and frequency domains.

2.2.1 Processing in time domain

In the time domain analysis, it is necessary to find the decay time of a sound wave. First, it is necessary to find the time T_s when the sound begins. The time when the sound pressure level becomes suddenly large defines T_s. The smallest value of t that satisfies the following equation is regarded as T_s.

$$\begin{cases} y(t+\Delta t) - y(t) > M \\ \dfrac{y(t+\Delta t)}{y(t)} > N \end{cases} \qquad (1)$$

where

$y(t)$: Amplitude at time t

Δt: Time interval unit

M,N : Threshold values

In indoor acoustics, the decay time is defined as when the amplitude decreases by 60dB, i.e. it decreases to 1/1000. However, analyzing the hammering sound in such cases as in outdoor environments or under the conditions where ambient noises exist, it is difficult to apply this criterion.

Here, we assume that averaged amplitude $\overline{y}(t)$ can be represented by the following equation, where $\overline{y}(t)$ is the average of the absolute values of $y(t)$ within a short duration.

$$\overline{y}(t+T_s) = A \times e^{-Bt} \qquad (t>0) \qquad (2)$$

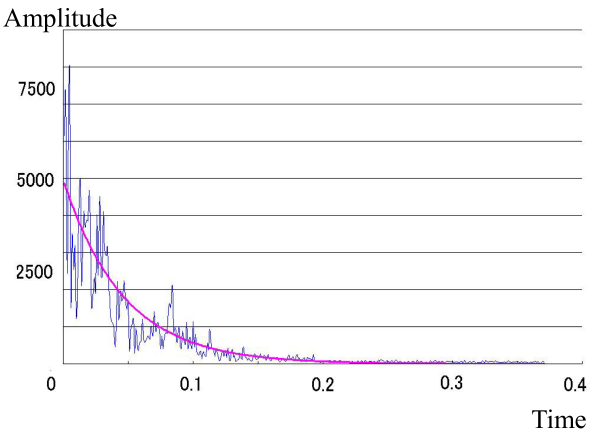


Fig.2 An example of raw sound wave and its approximation curve.

Then, we obtain the coefficient A and the index B in the above equation by using the least mean square method. The index B given by this step is used for sound signals discrimination in later process. An example of the result is shown in Fig.2.

2.2.2 Processing in frequency domain

In the frequency domain analysis, Fast Fourier Transform (FFT) is executed to obtain spectral data. In order to compare the spectral distribution, a frequency feature value V_f is calculated by Eq. (3), where a spread in frequency dependence is considered.

$$V_f = \frac{1}{A_s}\sqrt{\sum_{i=0}^{n-1}\left\{(f_i - \overline{f})^2 \times A_i^2\right\}} \qquad (3)$$

where

$$\overline{f} = \sum_{i=0}^{n-1} \frac{f_i A_i^2}{A_s^2}$$

$$A_s^2 = \sum_{i=0}^{n-1} A_i^2$$

f_i : i-th frequency

n : Number of data

A_i : i-th amplitude

2. 3 Image signal processing

The image frame corresponding to the event at time T_s is extracted from the image sequence file. Since the image was taken from behind the hammer, the exact hammering position is hidden by the hammer itself. So, in order to know the position accurately, it is required to calculate by integrating information about figures in the image, camera parameters including viewing distance and angles, and a 3-dimensional shape model of the hammer. On the other hand, how distinctively we can discriminate the hammering position dependence of the sound should be quantitatively clarified. Therefore, a further investigation is required on the accuracy concerning to the processing of the image signals.

2. 4 Generation of a thickness discrimination map

A thickness discrimination map is generated in advance to estimate the thickness of a board. Representative thick and thin portions are hammered, and sound signals for each hammering are captured. Then the decay index B and the frequency feature value V_f are calculated by the sound signal processing for each signal, and we obtain the B-V_f

figure having B and V_f on the horizontal and vertical axis, respectively. The mean coordinates of plotted points corresponding to the sampled thin and thick portions are calculated, respectively. Let such two points be P_0 and P_1. We draw a straight line L connecting points P_0 and P_1, and give each point on this line an attribute representing its thickness; e.g., the attribute is 0 at P_0 and 1 at P_1, and varies linearly between the two, while points outside P_0 and P_1 have the same value as those of P_0 and P_1, respectively. Then, we give all points on the line normal to the line L the same attribute value as that of the point on the line L.

2. 5 Estimation of thickness

Once the thickness discrimination map is generated, we can estimate the thickness of any portion of the board by comparing its values B and V_f to the map. Here, it should be noted that each hammering gives a thickness estimate and also its location on the board by the procedure of image signal processing.

In order to examine the thickness over the whole board, the process mentioned above needs to be done very densely on the board. However, this is difficult in practice and, if possible, takes a lot of time. Then, we hammer at points determined beforehand and interpolate points between each hammering point with the linear interpolating method

3 Experiments

In experiments, a digital video camera was used so that sound and image signals could be easily captured. A wood board shown in Fig.3 was used. The board size is 600mm by 600mm. The board is divided into two areas which have either of two thickness values, 12mm or 312m. An image of a hammering scene is shown in Fig.4. The board was hammered with almost the same strength. The signals downloaded to a personal computer were saved as the AVI file, and this file was divided into the sound signal file and the video signal file. The sound signal file was saved in the WAVE file format. Parameters of the WAVE file were set as follows.

- Sampling frequency : 44. 1kHz
- Number of channels : 1 (monaural recording)
- Number of bits: 16 bits

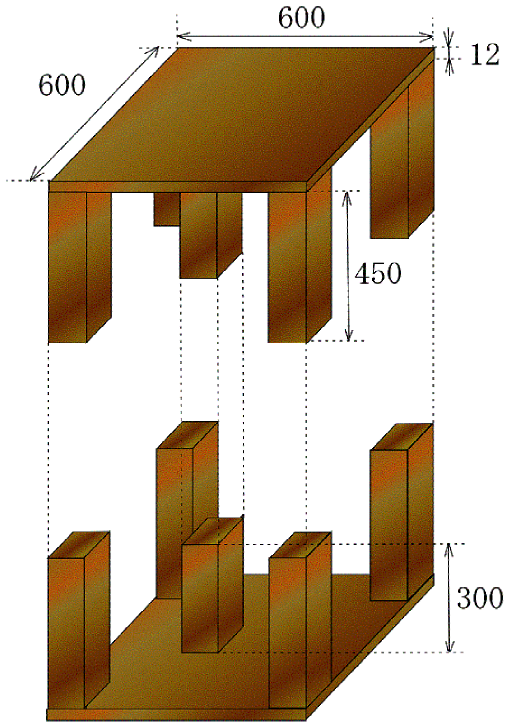


Fig.3 Experimental object.

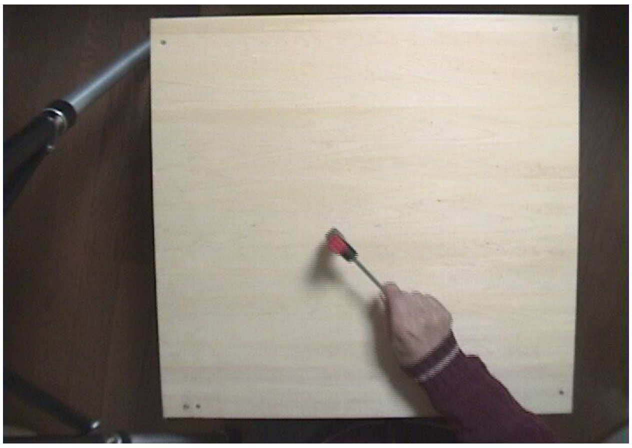


Fig.4 A hammering scene example.

Waveform examples are shown in Fig.5, where the recording period was 0.372sec. Figures 5(a) and 5(b) show that there is a differences between the waveforms for thick and thin portions. Examples of the frequency spectrum are shown in Fig.6. It is also shown that there is a difference between the frequency distributions.

The thickness discrimination map was generated by hammering thick and thin portions for 100 times, respectively. Table 1 shows the mean values of decay index B.

Table 1 Mean values of decay index B.

	Thick	Thin
Mean value of B	16. 7	25. 0

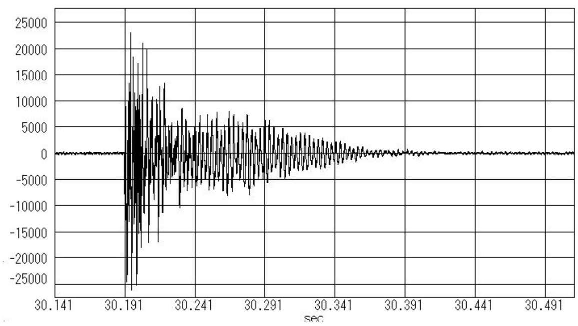
On executing FFT, the Hanning window was used, and its size was 16384 (=2^{14}), which was given by the recording period 0.372sec and the sampling frequency 44.1kHz. The frequency feature value V_f was calculated within the frequency band from 100 Hz to 1kHz, which gave specific frequency distribution. The mean values of V_f are shown in Table 2.

Table 2 Mean values of the features values of the frequency V_f.

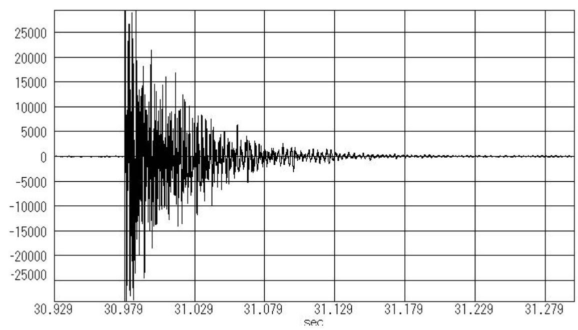
	Thick	Thin
Mean value of V_f	175	211

From Table 1, the decay index B has a tendency to become small when the thickness gets small. This can be explained by that a wave of high frequency decays faster than that of low frequency, and Fig.6 shows that a sound at thin portions consists of higher frequency waves than that at thick portions. Figure 7(a) shows the B-V_f figure in the experiment. Using the values of Table 1 and Table 2, the thickness discrimination map was generated as shown in Fig.7 (b). Here, the area shown in dark expresses thick portions, and the other expresses thin portions.

The thickness in each point on the board is inspected by using the thickness map of Fig.7 (b). By hammering several times at 7 by 7 points on the board, each thickness was estimated. Here, on the image processing stage, the hammering portions were simply determined by extracting the image of the hammer tail which was parallel to its head.



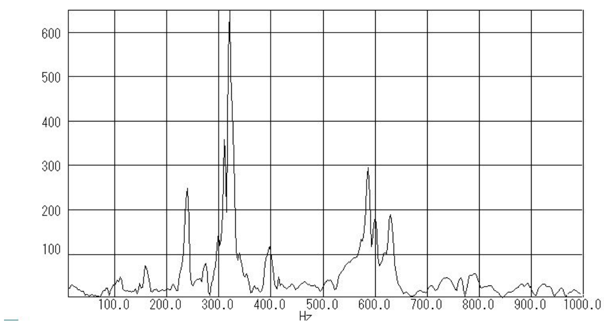
(a) Example in case of the thick portion.



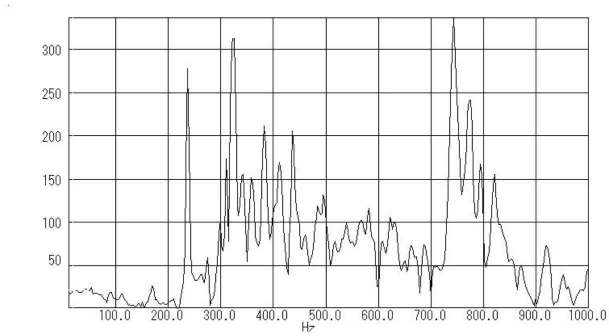
(b) Example in case of the thin portion.

Fig. 5 WAVE waveform.

Vertical axis : Amplitude, Horizontal axis : Time



(a) Example in case of the thick portion.

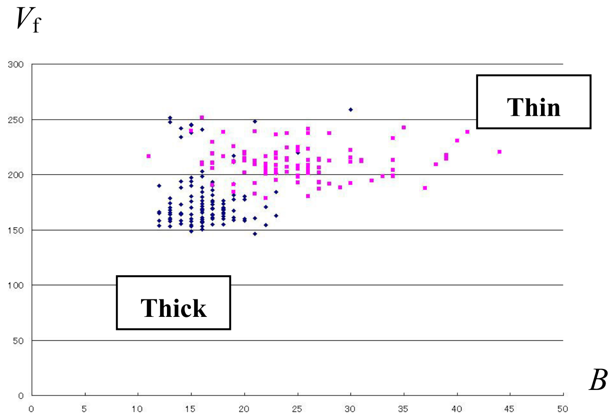


(b) Example in case of the thin portion.

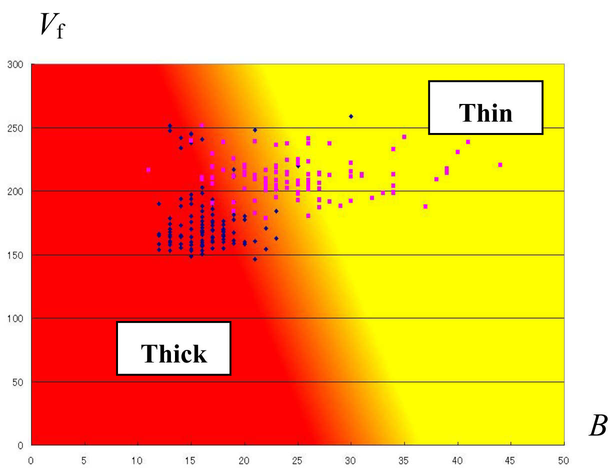
Fig. 6 Frequency spectrum with FFT.

Vertical axis : Amplitude, Horizontal axis : Frequency

Figure 8 shows the estimates for the actually hammered positions. Figure 9 shows the result by linear interpolation. By comparing of this result with the actual thickness distribution shown in Fig.9, it can be said that we have a good result for a preliminary study.



(a) B-V_f figure of the experiment.



(b) Generated thickness discrimination map.

Fig. 7 Thickness discrimination map.

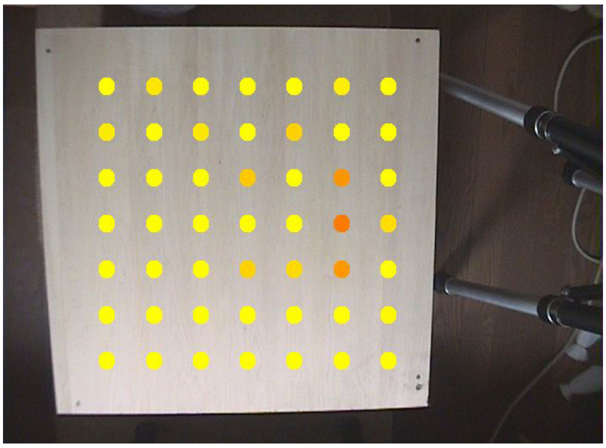
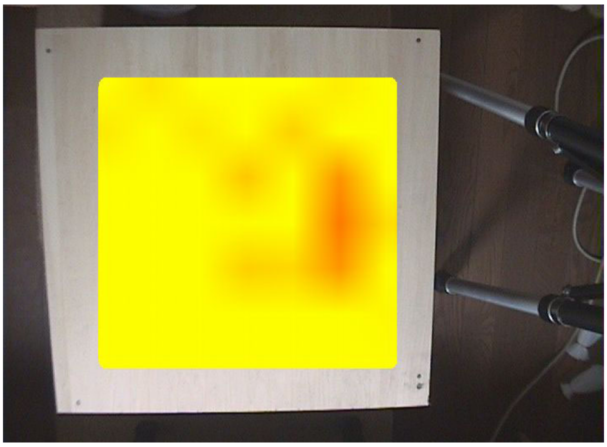
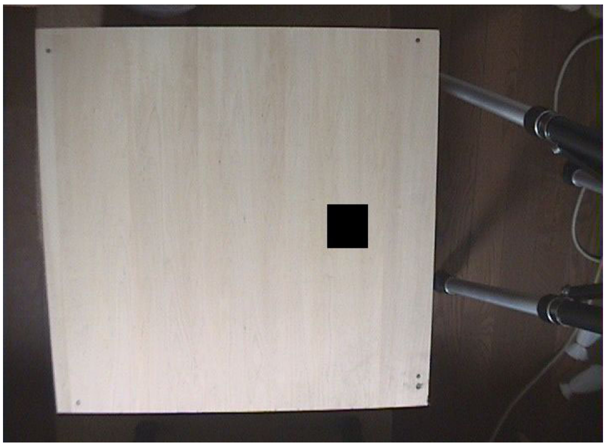


Fig. 8 Thickness of a wood board at hammering positions.

Thick portions are shown dark.



(a) Experimental result of the proposed method.



(b) State of the actual board.

Fig. 9 Thickness distribution of the whole wood boar.

Square in black : Actual thick area

4 Conclusions

In this paper, a hammering test system with a digital video camera and a personal computer is proposed. The system estimates the thickness discrimination map of a wood board by using the decay index and the frequency distribution, and determines simultaneously hammering positions by image signal processing. Validity of the method was confirmed by a preliminary experiment.

As a future work, we have to study cases under various conditions concerning to shapes and materials of both a board and a hammer. Another efficient feature should be investigated in order to make the method more accurate and robust. Acquisition of actual hammering positions by computer vision is also to be considered.

References

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