DEVELOPMENT OF AN ACOUSTICS-BASED DAMAGE DETECTION TECHNIQUE

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1. INTRODUCTION

The number of deteriorating reinforced concrete structures is increasing in Japan. As one of the common methods of large-scale deep inspection, the hammering test has attracted the attention of researchers.

This paper proposes a novel method for damage analysis, which extracts the fundamental frequency of the audio signal as a feature and uses the Dynamic Time Warping (DTW) algorithm (Tavard et al., 2012) to compare the similarity of two hammering points to find the location of damage in a series of data and distinguish the types of damage.

The general sound is composed of a series of vibrations with different frequencies and amplitudes emitted by the vocal body. Among these vibrations, there is a vibration with the lowest frequency, and the sound emitted by it is the fundamental frequency. The damaged part and the non-damaged part of concrete are completely different in quality and shape. Since the different fundamental frequency of the sounding body will also be significantly different, it can be used as a suitable feature to distinguish between damaged area and healthy area. The results also confirm that this method can distinguish different types of damages.

2. METHODOLOGY

2.1 Pitch Detection Algorithm for Fundamental Frequency

In this paper, the spectrum/time pitch detection algorithm by is selected in the PDA based upon a combination of time domain processing using an autocorrelation function such as normalized cross correlation, and frequency domain processing utilizing spectral information to identify the pitch. Then, among the candidates estimated from the two domains, a final pitch track can be computed using dynamic programming. The advantage of these approaches is that the tracking error in one domain can be reduced by the process in the other domain.

Fig. 1 The flowchart of Fundamental Frequency

The feature extraction through fundamental frequency involves five main steps, including pre-emphasis (Pre-Emphasis, Framing, windowing), short-time average energy and autocorrelation, as shown in Figure 1. The variation of autocorrelation analysis can be expressed by the following Eq (1).

$$R_i(k) = \sum_{m=1}^{N-m} x_i(m) x_i(m+k) \tag{1}$$

Where $x_i(m)$ is the sample of signal of the i-th frame for the signal sequence of length N, $x_i(m+k)$ is the sample time-shifted k seconds.

2.2. Dynamic Time Warping

Dynamic time warping (DTW) is a much more robust distance measure for time series, allowing similar shapes to match even if they are out of phase in the time axis. For instance, similarities in walking could be detected using DTW, even if one person were walking faster than the other, or if there were accelerations and decelerations during an observation. Because of this flexibility, DTW has been applied to temporal sequences of video, audio, and graphics data — indeed, any data that can be turned into a linear sequence can be analyzed with DTW.

2.3 DATA

As shown in Figure 2, foam was pre-embedded at 20-26cm of the concrete sample with a total length of 40cm to simulate the void inside the concrete. Take a hammering point every 2cm from left to right and hammering sound data are recorded 100 times by 192kHz sampling frequency at each point as shown in Figure 3.

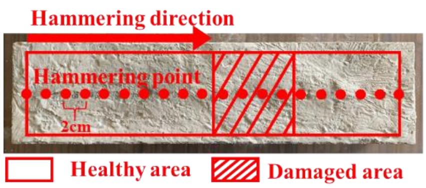

Fig. 2 Concrete sample

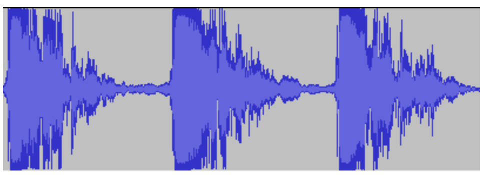

Fig. 3 The sound signal recorded by the microphone.

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3. RESULTS AND DISCUSSION

3. 1 Result of fundamental frequency

The extracted fundamental frequency is shown in Figure 4, and then the first peak of each point is extracted to obtain the curve as shown in Figure 5. As shown by the trend line, there is a certain functional relationship between distance and the first peak. In the internal damage experiment, as the distance gradually approaches 20-26 cm of the damaged area, the frequency gradually decreases, and after passing through the damaged area, the frequency gradually increases. As shown in Figure 6, this study has also done a surface damage experiment, taking 5 points every 2cm on a concrete sample of 12cm long, and the surface damage is located at 6cm. In surface damage, as the distance is closer to the damage, the frequency increases, and the frequency gradually decreases after passing the damage point. In the internal damage experiment, although the first peak has a trend, more effective peaks are needed if the location of the damage needs to be accurately located.

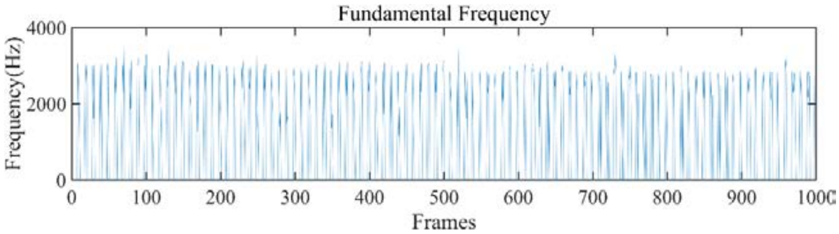

Fig. 4 Fundamental frequency

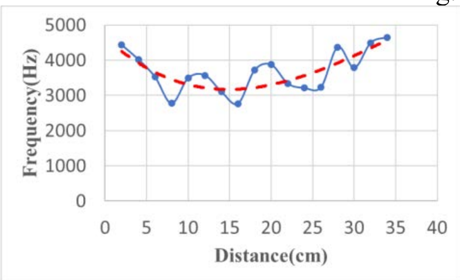

Fig. 5 The first peak curve of internal damage

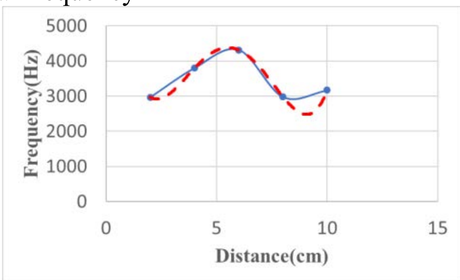

Fig. 6 The first peak curve of surface damage

3. 2 Result of improved method

Therefore, we imported the DTW algorithm to compare the similarity of the two fundamental frequencies frame by frame. Taking the first point as a constant and the other points as variables, record the similarity between each point and the first point to obtain the distance/score curve as shown in Figure 7. In terms of images, the scoring curve drops sharply around 20-26cm. Through calculation, it can be concluded that the arithmetic average deviation of the fluctuation degree of 1-19 is 5.826, while the average fluctuation degree of the four points of 20-26cm is as high as 12.380.

Through the surface damage experiment, the distance/score curve as shown in Figure 8 is obtained, and the curve dropped significantly at 5 cm of the damaged area. The fluctuation range is 6.174, and the fluctuation degree of the damaged area is as high as 13.668. Whether it is from the numerical value or the image curve, the improved method can more clearly and accurately identify healthy areas and damaged areas in the identification of internal damage and surface damage.

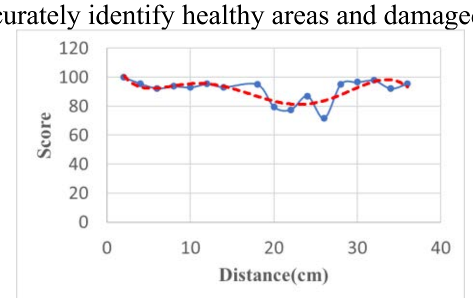

Fig. 7 Scoring curve of internal damage

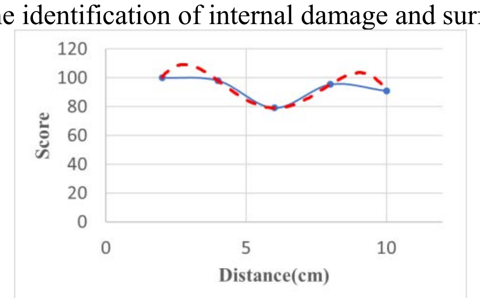

Fig. 8 Scoring curve for surface damage

3. 3 Distinguishment of types of damaged concrete

In terms of distinguishing different types of damage, through the comparison of the curves in Figure 7 and Figure 8, it is found that the slopes of the two different types of damage curves from the healthy area to the damaged area are completely different. Therefore, different types of damage can be distinguished by the slope.

4. CONCLUSIONS

In this study, we first confirmed in 3.1 that the fundamental frequency of the test point is related to the distance between the damaged area. Then through the comparison of 3.1 and 3.2, it was proved that this method can more accurately distinguish the healthy area and the damaged area inside the concrete. Finally, it was confirmed in 3.3 that this method can also distinguish different types of damage.

5. REFERENCES

F Tavard, Simon A , Hernandez A I , et al. Dynamic Time Warping[J]. 2012:198-203.