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Estimation of Water Stress of Plant by Vibration Analysis of Leaf with High Speed Camera

ハイスピードカメラを用いた葉の振動解析による植物の水ストレスの推定

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1. Introduction

In order to develop water-saving systems for advanced precision agriculture, we have been studying the visualization of water distribution in soil using the difference of sound velocity of soil [1]. On the other hand, we have been also trying to estimate the water stress of plant by vibration analysis of leaf, and so far, we have investigated the relationship between the natural frequency and the water content of a picked leaf by measuring its vibration displacement with laser displacement sensor together with the weight of leaf [2].

However, the motion of living leaf on the plant consists of other vibrations than that of leaf itself, because the leaf will move with its leafstalk. Moreover, it includes several kinds of vibration modes such as torsion vibration. Therefore it is necessary to decompose the vibration into fundamental vibrations.

Thus, in this study, we tried to measure the vibration displacement of a leaf at several points simultaneously with a high speed camera in order to study the vibration modes of a living leaf.

2. Experimental setup

The experimental setup was as shown in Fig. 1. We used "Komatsuna" plant (Brassica rapa var. perviridis) which was cultivated with the culture soil put in a planter during about a month.

First, we chose a young leaf and pushed it with the acoustic radiation force of ultrasound which is irradiated from a parametric speaker AS101AW3PF1 (Nippon Ceramic Co., Ltd.). The speaker was driven by 0.1s of 1$V_{p\text{-}p}$ 40 kHz continuous sinusoidal signal using a function generator AFG3022 (Tektronix Inc.). The distance between the speaker and the leaf was about 150 mm. As the result the leaf was pushed during about 0.5s and then the dumping vibration began.

Next we photographed the dumping vibration by a high speed camera HAS-L1 (Detect Corp.) with frame rate 500 fps, shutter speed 1/000s and the window size 640×480. A strobe light synchronized with the frame rate was also used for lighting the leaf. The measuring time was about 10s. The distance between the camera and the leaf was about 450 mm.

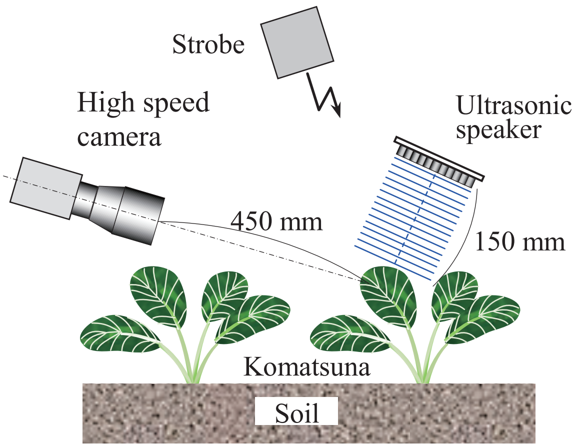

Fig. 1. The experimental setup.

3. Data analysis

Figure 2 shows one frame of the movie photographed by the high speed camera. As shown in Fig. 2, we chose 5 points P1~P5 to track their vibration displacements of a leaf in this study. Point P1 is the center of the leaf, P2 is right wing, P3 is near the leafstalk, P4 is left wing, and P5 is near the tip of the leaf. The motion analysis was performed with the motion analysis software DIPP-Motion V ver.1.0 (Detect corp.).

We employed the correlative tracking method for tracing the displacement of a target point of the leaf. The square drawn in the figure means the region of template (64×64 dots) (inner one) and the search area (96×96 dots) (outer one) of point P1. The regions of the other points were chosen in the same way.

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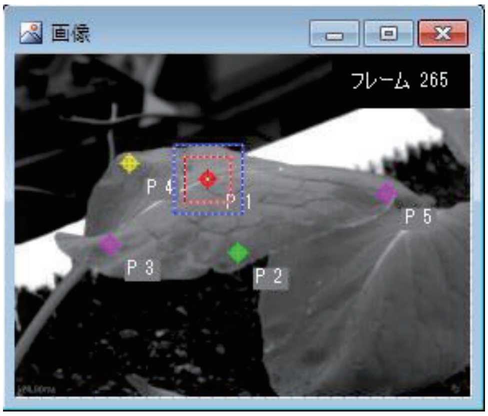

Fig. 2. Example of the target points of a leaf.

The traced data were exported as so called CSV file and then analyzed to find the natural frequency of this leaf and leafstalk system by calculating power spectral density of the vibration with FFT package of the Scilab (one of the open source software for science and technology).

4. Result and Discussion

Figure 3(a) shows a typical result of vibration displacement. This time, a kind of beat was observed at several points. This means there exists to different vibration modes which have near natural frequency each other. This behavior is also confirmed in the power spectral density shown in

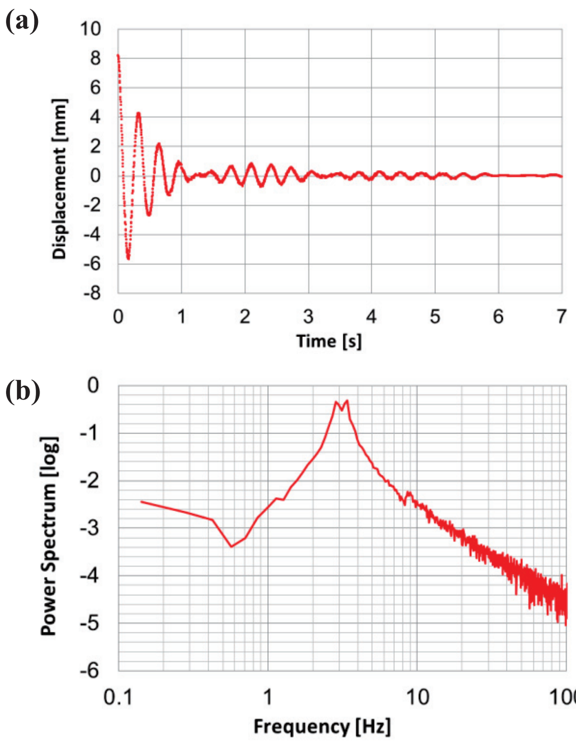

Fig. 3. A typical result of the vibration measurement of a leaf. (a)Vibration displacement, (b) its power spectral density.

Fig. 3(b) as the twin peaks around 3 Hz. The same phenomenon was observed at the point P4.

In order to extract the natural frequency of bending vibration of leaf itself, we examined an angle $\theta = \angle P_3P_1P_5$, which is an angle between vector $\overrightarrow{P_3P_1} = (x_1, y_1)$ and $\overrightarrow{P_1P_5} = (x_2, y_2)$ given by

$$\theta = \cos^{-1} \frac{x_1x_2 + y_1y_2}{\sqrt{x_1^2 + y_1^2}\sqrt{x_2^2 + y_2^2}} . \qquad (1)$$

As a result, we obtained the power spectral density of the angle variation as shown in Fig. 4. From this graph, we can see small peaks of 6 Hz and 8 Hz. These peaks are expected to be the natural frequency of vending vibration of the leaf. Similar results were obtained among P2, P1, and P4, *i.e.* the angle $\angle P_2P_1P_4$.

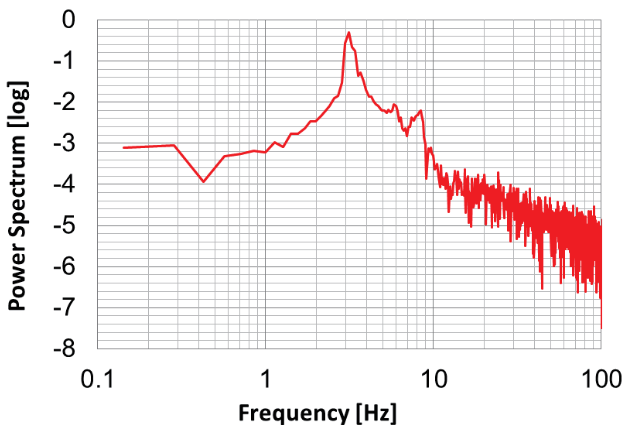

Fig. 4. Power spectral density of the variation of the angle $\theta = \angle P_3P_1P_5$.

5. Conclusion

In this study, the beat of two different vibrations whose natural frequencies were similar to each other was observed. However, the separation of these to modes was not successful yet. On the other hand, the natural frequency of vending vibration was estimated from the vibration of bending angle. In the future work, we are going to study the relationship between water stress of plant and the frequency of each vibration mode.

Acknowledgment

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