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Estimation of water stress of plants by measurement of diurnal variation of natural frequency of leaves using ordinary CCD camera

通常の CCD カメラを用いた葉の固有振動数の日周変動測定による
植物の水ストレス推定

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1. Introduction

In order to control optimum irrigation, we are investigating a method to estimate water stress of plants non-invasively and in real time by measuring the change of the natural frequency of leaf[1], and so far we have found the following natures. First, the natural frequency of leaf sharply decreases when the leaves wither strongly[2]. Second, even in a healthy state, the natural frequency of leaf varies diurnally, that is, it tends to rise during the day and decreases at night[3]. And last, when the water stress increases, the tendency reverses, that is, it tends to decrease during the day and to increase at night as shown in Fig. 1.

In addition, by simultaneous multipoint analysis using a high-speed camera and three laser displacement sensors, the leaf vibration was divided into "the oscillation of a whole leaf due to deflection of the petiole" and "the deflection oscillation of the leaf blade itself", and it was found that the former is suitable for the estimation of water stress of plant[4].

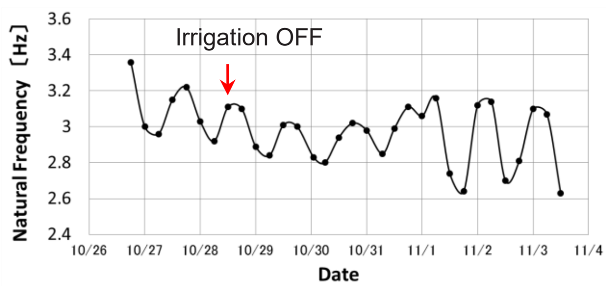

Fig. 1. Diurnal change of natural frequency of leaf.

Incidentally, since the natural frequency of "the oscillation of a whole leaf due to deflection of the petiole" is at most about 10 Hz, a normal CCD camera (30 fps) will be sufficient, even without using a high-speed camera. Therefore, in this research, we considered the 24-hour measurement of the natural frequency of leaf using a normal CCD camera.

2. Experimental setup

The experimental setup was as shown in Fig. 2. As a specimen, "Komatsuna" plant (*Brassica rapa* var. *perviridis*) was used and a leaf was vibrated by the acoustic radiation pressure generated by the ultrasonic sound source below, and the subsequent damped vibration was acquired with a normal CCD camera.

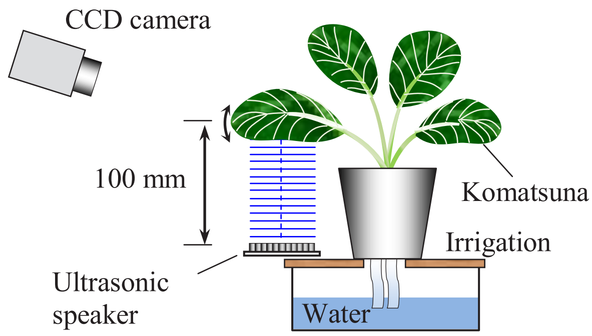

Fig. 2. The experimental setup.

The specimen was cultivated with the culture soil in a planter by the bottom irrigation using a water absorption sheet (Toyobo, Cosmo A-1). The lighting was done with fluorescent lamps at about 9000 lx from 6:00 to 18:00 during about a month.

As an ultrasonic sound source, we employed a parametric speaker (AS101AW3PF1, Nippon Ceramic Co., Ltd.), and 0.1 s of 1 $V_{p\text{-}p}$ 40 kHz continuous sinusoidal signal was applied using a function generator (AFG3022, Tektronix Inc.). The distance between the speaker and the leaf was about 100 mm. Thereby, the leaf was pushed during about 0.5s and then the dumping vibration began.

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Next we recorded the video image of dumping vibration of leaf by a CCD camera. The camera used this time was a general-purpose CCD camera (ELECOM UCAM-DLK 130 TWH), whose frame rate is 29 fps, shutter speed is auto, image size is 320 × 240 dots, and image format is 16-bits WMV.

The measuring time was about 10s. The distance between the camera and the leaf was about 450 mm.

3. Data analysis

Figure 3 shows certain frame of the movie taken by the CCD camera. We chose a target point P1 as shown in Fig. 3 and its motion was analyzed with the motion analysis software (DIPP-Motion V ver.1.0, Detect corp.). We employed the correlative tracking method in order to trace the displacement of point P1 on the leaf. The size of the template was 32×32 dots and the search area was 64×64 dots.

The traced data were exported as "CSV" file and then it was read into Excel, smoothed by Savitzky-Golay method (m = 4), and last it was analyzed by calculating power spectral density of the vibration with FFT package of the Scilab to find the natural frequency of leaf.

Fig. 3. Example of the target points of a leaf.

4. Result and Discussion

Figure 4 shows the temporal change of the y coordinate of the point of interest P1. For the first 0.6 seconds, the leaves were pushed up by about 1 to 2 mm due to the acoustic radiation pressure, but after 0.6 seconds when the acoustic radiation pressure disappeared, a clean damped oscillation could be observed.

Figure 5 shows the power spectrum of the damped oscillation part from after 1 second. It can be seen from the figure that the natural frequency of this leaf is about 3.4 Hz. That is, 29 fps was sufficient sampling frequency for power spectrum estimation.

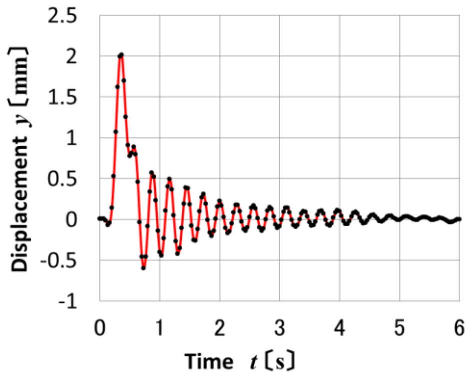

Fig. 4. A typical result of vibration measurement of leaf.

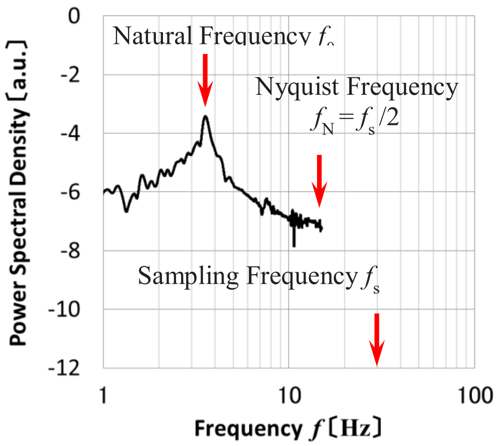

Fig. 5. Power spectral density of the variation

5. Conclusion

As a result of vibration analysis of leaf using an ordinary CCD camera with a frame rate of 29 fps, we found that it has sufficient accuracy if the frequency is low like the natural frequency of leaf.

In the future, by applying this method to automatic measurement system of leaf vibration throughout the night, we are going to investigate whether the diurnal change of natural oscillation of the leaf can be reproduced like the result measured by the laser displacement meter.

Acknowledgment

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References

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