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An analysis of natural frequency of leaf by the fluctuation of CCD camera image and the estimation of water stress of plant

CCD カメラ画像のゆらぎによる葉の固有振動数解析と植物の水ストレス推定

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1. Introduction

In order to perform the optimal irrigation control, we are investigating a method to estimate the water stress of plant non-invasively and in real time by the change of natural frequency of leaf [1, 2]. And we found so far that the natural frequency of healthy leaf (deflection vibration of the petiole) fluctuates with one day cycle, that is, it increases in the daytime and decreases at night. While, we also found that the above tendency is upside down, that is, the natural frequency decreases in the daytime, as the water stress increases.

Therefore, using this property, it is expected to be able to detect the water stress of plant before the drooping of leaf. Thus we measured the natural frequency of leaf using a high-speed camera or a laser displacement sensor. But as this research progresses, we found that even a general-purpose CCD camera (30 fps) is enough to determine the natural frequency of leaf because its frequency is about 10 Hz at most [3-5].

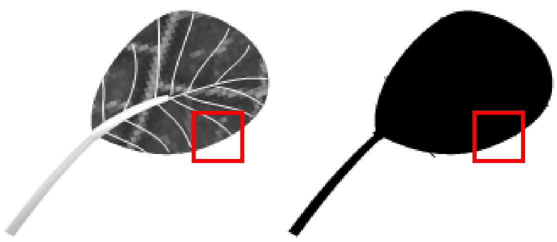
Nevertheless, since the correlation tracking method was still used to observe the vibration of leaf, it was difficult to automate the measurement. Then, in order to realize the automatic measurement, we proposed a new method to obtain the natural frequency of leaf by measuring the fluctuations in the brightness of CCD camera image due to the vibration of leaf in this study.

2. Method

When a leaf vibrates due to the deflection of petiole, the position of the leaf displaces. Therefore, assuming the rectangular region (box) like **Fig. 1** for example, the average pixel value in the region fluctuates with the leaf vibration. Thus, the natural frequency of the leaf can be obtained from this fluctuation. In this research, we tried two kinds of average of pixel value in the region. One is the grayscale average using grayscale image as shown in Fig.1 (a). The other is the binarization average using binarized image made by extracting the leaf by color information as shown in Fig.1 (b). The size of the rectangular area was 40 × 40 dots.

As a specimen, "Komatsuna" plant (*Brassica rapa* var. *perviridis*) cultivated with soil during a month in a pot was used. The water was supplied to the cultivation soil with water supply sheet (Toyobo, Cosmo A-1) from the bottom. The lighting was done from 6 am to 6 pm with the fluorescent light whose light intensity was about 150 μmol/m^2/s.

A leaf of komatsuna was vibrated by the acoustic radiation pressure of ultrasonic sound of 40 kHz with the parametric speaker (Nippon Ceramic Co., Ltd., AS101AW3PF1). And the damping oscillation of the leaf was captured with a general-purpose CCD camera (ELECOM, UCAM-DLK 130 TWH). The maximum frame rate of the CCD camera was 30 fps, and the image size was 640 × 480 dots. Then the change of the average pixel value within the rectangular region was calculated and saved it as a CSV file. The data acquisition was performed in real time with a self-made program. The natural frequency of leaf was calculated from the CSV data with the Fourier analysis using a free soft Scilab.



(a) Grayscale image (b) Binarized image

Fig. 1 The rectangular region for average

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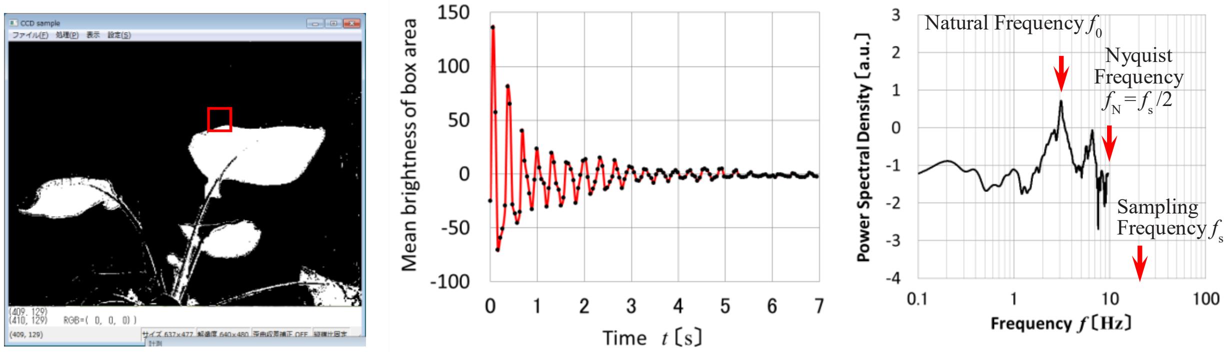

(a) Binarized image (b) Vibration displacement (c) Power spectral density

Fig. 2 A result using the binarization average

3. Result

Figure 2 shows an experimental result using the binarization average. In this figure, (a) shows a frame image, (b) shows the temporal change of the average pixel value in the rectangular area of (a), and (c) is its power spectral density. The black dots in (b) are the measurement points, thus a typical damping curve was obtained. Almost the same result was obtained for the grayscale average.

But, in the grayscale average, the LED light was necessary, because the moire patterns appeared under normal fluorescent lamps. While in the binarization average, the extraction of leaf was sometimes failed depending on the condition of the lighting. Also, due to the influence of blinking near the threshold, the random noise was seen in the waveform. In addition, because the process is somewhat heavy, the frame rate did not reach 30 fps but only about 20 fps. Thus, it was found that measurement of the natural frequency exceeding 10 Hz is difficult to the binarization average.

Figure 3 shows the temporal variation of natural frequency using the binarization average. The black dots refer to the raw data measured. As shown in this figure, there are some largely deviated points. However, these points are not thought to represent the correct natural frequency, because the original waveform of these points did not show damping curve. Thus, we removed these points by applying the median filter (front and back 6 points). The result is drawn with a red line. Also in 7/23, the damping curve was not so clear that the frequencies were not desirable. But excepting for these points, the diurnal variation of natural frequency was almost confirmed.

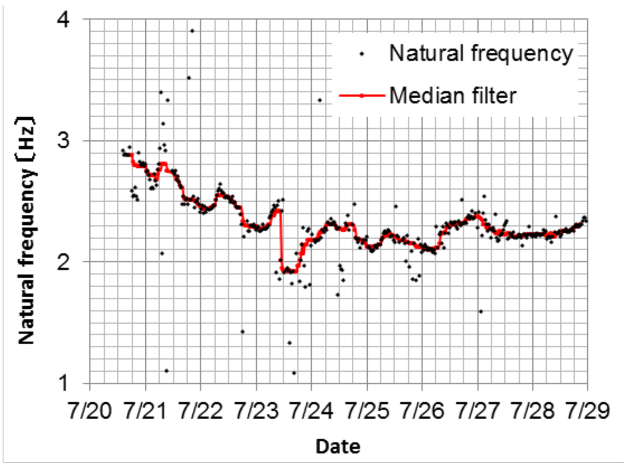

Fig. 3 Temporal variation of natural frequency of leaf by the binarization average

4. Conclusion

It was verified that it is possible to obtain the natural frequency of leaf by using the method of measuring the change of the average pixel value in the region proposed in this research. However, the measurement of damping curve sometimes failed due to the rectangular area being out of range and so on.

In the future, we will improve the program so as to reduce the failure in measurement. And, we will verify whether the water stress of plant can be detected sensitively by measuring the diurnal variation of the natural frequency of leaf with this method.

Acknowledgment

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References

1. M. Sano, *et al.*; Jpn. J. Appl. Phys., **52** (2013) 07HC13.
2. M. Sano, *et al.*; Acoust. Sci & Tech., **36** (2015) 248.
3. M. Sano, *et al.*; Proc. of 35th Symposium on UltraSonic Electronics, 1P2-15 2014.
4. M. Sano, *et al.*; Proc. of 36th Symposium on UltraSonic Electronics, 3P2-5 2015.
5. M. Sano, *et al.*; Proc. of 38th Symposium on UltraSonic Electronics, 3P2-2 2017.