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Analysis of Bioelectrical Potential When Plant Purifies Air Pollution

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SUMMARY Some plants have air purification ability. This purification ability of plants is considered a promising method for indoor air purification because of the low cost and high purification performance. Therefore, several studies have been carried out to investigate the relationship between the air purification ability of plants and environmental conditions. Nevertheless, the purification mechanism and process have not been clarified yet. In this paper, we investigated the air purification process in plants by bioelectrical potential analysis using linear and nonlinear analysis methods. First, we showed that two types of plants have a high air purification ability; Schefflera and Boston fern. Next, we measured AC bioelectrical potential during the purifying process of plants for pollutant gas. Then, we evaluated the power spectra of time series data of the bioelectrical potential. We found that the power spectra shifted to a lower level after gas injection over all frequencies. Thus, the higher power spectrum came from possible higher physiological activities of the plant. Finally, we introduced a nonlinear analysis method from the dynamical system theory. We transformed the time series data of the potential to a higher dimensional state space using a delay coordinate, which is often used in the field of nonlinear time series analysis. The results show that the orbits in the reconstructed state space have a large variation in gas injection. These experimental results suggest that the measurement of bioelectrical potential could become a useful method for evaluating the air purification ability of plants.
key words: *air purification ability of plant, bioelectrical potential, power spectra, dynamical system, delay coordinate*

1. Introduction

Recently, it has been widely recognized that Sick House Syndrome is caused by various chemical substances such as formaldehyde and volatile organic compounds, generated from building materials and office automation apparatuses. Therefore, various studies have been carried out to investigate how to remove these pollutant gases and clarify that some types of plant have air purification ability [1], [2]. This purification ability of plants is considered a promising method for indoor air purification because of the low cost and high purification performance. The air pollution purification ability of plants is influenced by various growth conditions, such as soil, temperature and light [3], [4]. We also confirm that the gas purification rate is faster under a light illumination condition than under a dark condition [5].

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Nevertheless, even with these research studies on the air purification ability of plants, we still have no clear concept of the purification mechanism and process.

In this paper, we investigate the air purification process of plants by bioelectrical potential measurement. We have already reported the behavior of the DC components of bioelectrical potential when plants purify the pollutant gas [5], [6]. In these studies, we show that the DC bioelectrical potential gradually decreases corresponding to the decrease in pollutant concentration (Fig. 1).

In this paper, we measured AC components under both the light illumination and dark conditions and investigated the influence of gas injection. The AC components were estimated by calculating power spectra. In addition, we observed the difference in time series behavior under these conditions from the viewpoint of nonlinear dynamical system theory. Namely, we transformed the time series of the bioelectrical potential in a reconstructed state space before and after gas injection. These results suggest that the measurement of the bioelectrical potential could become a useful method for evaluating the air purification ability of plants.

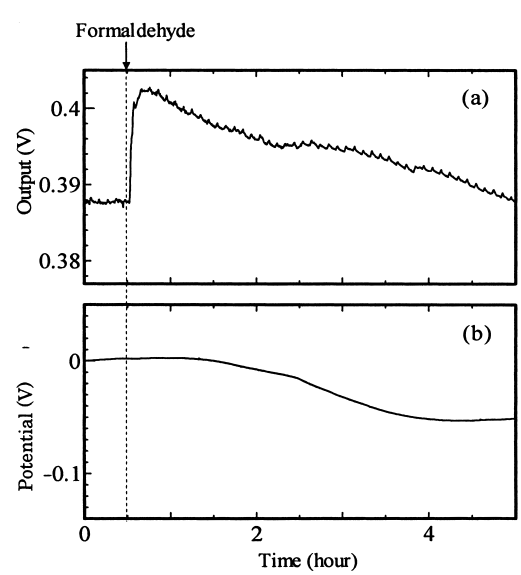


Fig. 1 (a) Gas sensor response and (b) DC bioelectrical potential change of Schefflera of a leaflet for formaldehyde injection under light illumination. The ordinate of (b) is the absolute value of the potential.

2. Experiments

Figure 2 shows the measurement system of the bioelectrical potential of plants. Formaldehyde (initial concentration: 65 ppm), which is one of the principal pollutant chemicals, was injected into the sealed chamber (volume: 230 liters) using a microsyringe. The air pollution purification effect and bioelectrical potential of plants were measured under controlled temperature and humidity (22°C and 80% relative humidity). Two types of electrode for measuring electroencephalographic potential were used for bioelectrical potential detection; the first is a disk-type electrode which has good adhesion with the plant surface and low-noise characteristics against surrounding disturbances; the second is a needle-type electrode convenient for the measurement of a small area. The disk-type electrode was used for the measurement of leaflets and the needle-type electrode for the measurement of stems and branches. By the measurement of the leaflets, we detected the potential between the base of a leafstalk (the negative electrode) and the surface of the leaflet (the positive electrode). For the measurement of gas concentration, a combustible gas sensor (CGS) of tin dioxide type was used. The gas sensor is on the market and has a high sensitivity to various air pollutant gases. The sample plants were some Schefflera (*Schefflera arboricola* 'Hong Kong': Fig. 3(a)) and some Boston fern (*N. exaltata* cv. Bostoniensis: Fig. 3(b)). The height of the plants was approximately 20 cm. The bioelectrical potential was detected using a high input impedance (> 1 GΩ) digital multimeter under both the light illumination and dark conditions. The light source used was a Biolux fluorescent lamp (NEC Corp.), which emits light energy of wavelengths 400 to 500 nm and 600 to 700 nm needed for growing plants.

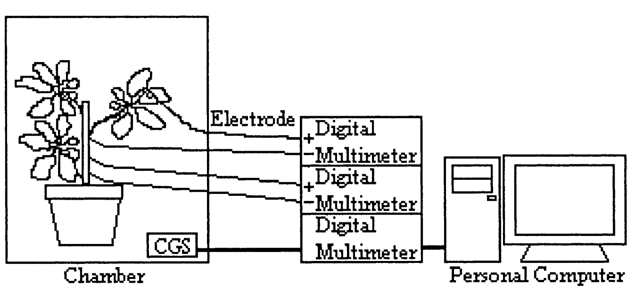
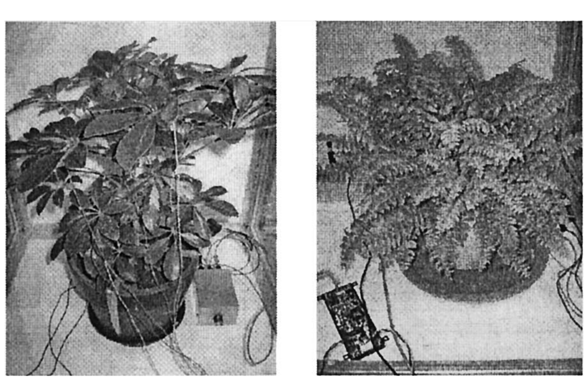


Fig. 2 Measurement system of bioelectrical potential and purification ability of plants.



(a) Schefflera. (b) Boston fern.

Fig. 3 Sample plants in this experiment.

3. Results and Discussions

3.1 Air Purification Ability of Plants

We estimated the air purification ability of plants by injecting formaldehyde under both light illumination and dark conditions. Figure 4(a) shows the gas sensor response without a plant. The gas sensor response increased by the gas injection and it remained almost constant. On the other hand,

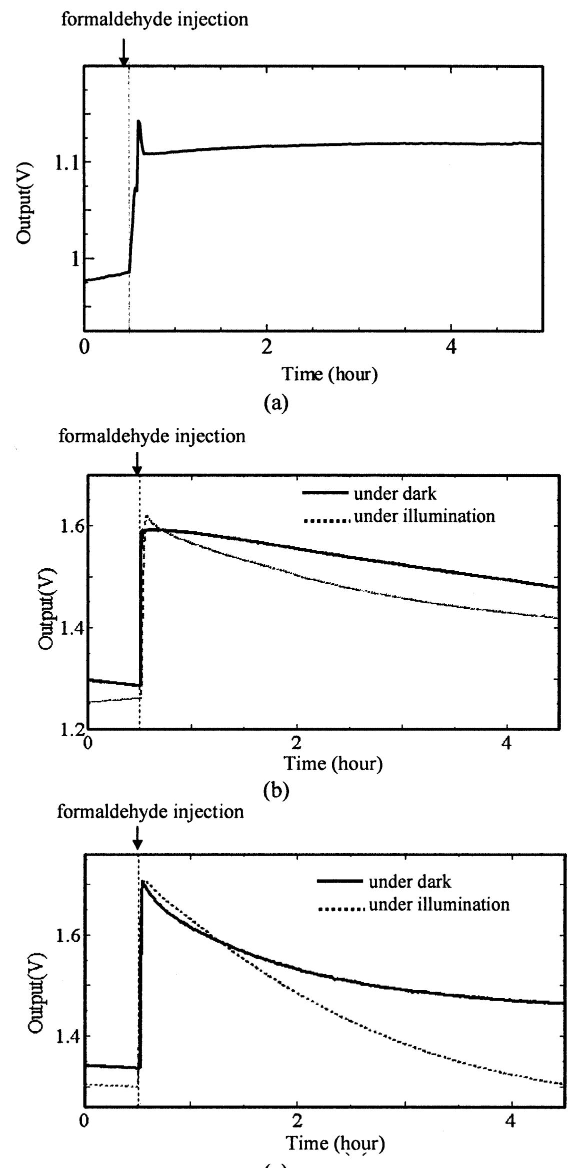


Fig. 4 Gas sensor response for formaldehyde injection. (a) Without plant, (b) with Schefflera and (c) with Boston fern.

Fig. 4(b) shows the gas sensor response when Schefflera was put into the chamber. Immediately after the gas injection, the gas sensor response increased and gradually decreased corresponding to the gas concentration removal by the plant. In Fig. 4(b), the solid line shows the output response under the dark condition, and the dashed line shows the output response under the light illumination condition. The gas purification rate was faster under the light illumination condition than that under the dark condition. The results suggest that photosynthesis activity enhanced the purification abilities.

We also observed similar tendencies in the gas sensor responses in Boston fern as shown in Fig. 4(c). The gas purification rate was also faster under the light illumination condition than under the dark condition. However, compared with Schefflera, the purification ability of Boston fern was higher than that of Schefflera since the purification rate was faster than Schefflera.

3.2 Frequency Spectrum of Bioelectrical Potential of Plant to Pollutant Gas

The bioelectrical potential of plants shows rapid temporal fluctuation (AC component) superimposed on a DC component (long-term change) [7]. In this paper, we extended our research to the analysis of the AC component because the AC components have more information than the DC component.

Figure 5 shows an example of the time series data of bioelectrical potential under the light illumination condition measured at a sampling interval of 0.1 sec. The time series data looks irregular as shown in Fig. 5. In order to extract a characteristic feature of the time series, we use a signal processing method. Thus, we estimated the power spectra of the potential using the Fourier transform by the Blackman-Tukey method [8].

The power spectra of Schefflera are shown in Fig. 6 under both the light illumination and dark conditions. These results show that the log-log plots of the power spectra of the plant were well approximated by a straight line. Comparison of the power spectra of the light illumination and dark conditions indicated that the power level under the light illumination condition was higher than that under the dark condition. This may originate from plant activity of, for example, photosynthesis and transpiration under the light illumination condition. The results of Fig. 6 also show that the power spectra has approximately a $1/f^2$ characteristic, although they had slight fluctuations of the slope depending on the environmental conditions such as temperature and light illumination conditions. The 1/f characteristic of the bioelectrical potential of plants has already been reported and our results were almost consistent with the report [9].

Figure 7 shows the power spectra for the time series data of Schefflera under the light illumination condition both before and after the gas injection. In Fig. 7(a), we found that the power spectra shifted to a lower level after the gas injection over all frequencies, recovered gradually, and finally almost reached its initial level after approximately two hours as shown in Fig. 7(b). This recovery may correspond to the gas reduction procedure.

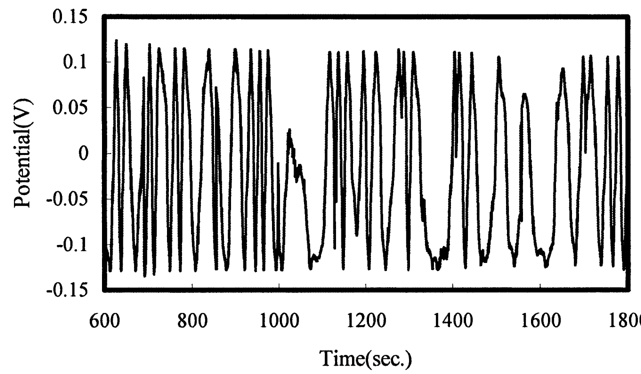


Fig. 5 Time series data of AC bioelectrical potential response of leaflet under light illumination condition.

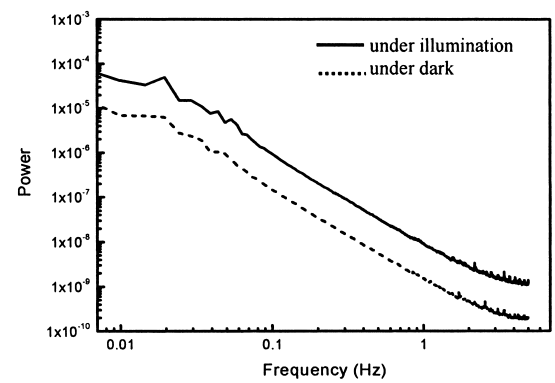


Fig. 6 Power spectrum of bioelectrical potential of Schefflera under illumination and dark conditions.

Next, Fig. 8(a) shows the power spectra of Boston fern under the light illumination condition before and immediately after the gas injection. Although, the power level was different from that of Shefflera shown in Fig. 7(a), it had a similar decrease after the gas injection. Then, the response returned to almost the initial value after approximately one hour as shown in Fig. 8(b). These results show that Boston fern purified the air more effectively than Schefflera.

Although we found that the plants had the purification ability for the pollutant gas, which was quantified by the variation in the level of the power spectra under the light illumination condition, under the dark condition, the power spectra of the bioelectrical potentials of both Schefflera and Boston fern hardly changed in our experiment. We have two reasons for such variation; the first one is that the plants have less activity under the dark condition, because of the lower photosynthesis; the second one is that it was impossible to detect the variation only by the spectral estimation method. It is true that if the observed time series is nonlinear, it is impossible to evaluate the time series using only the power spectral estimation method because it is a linear method. In order to investigate the possibility, we introduced a nonlinear method in the following section.

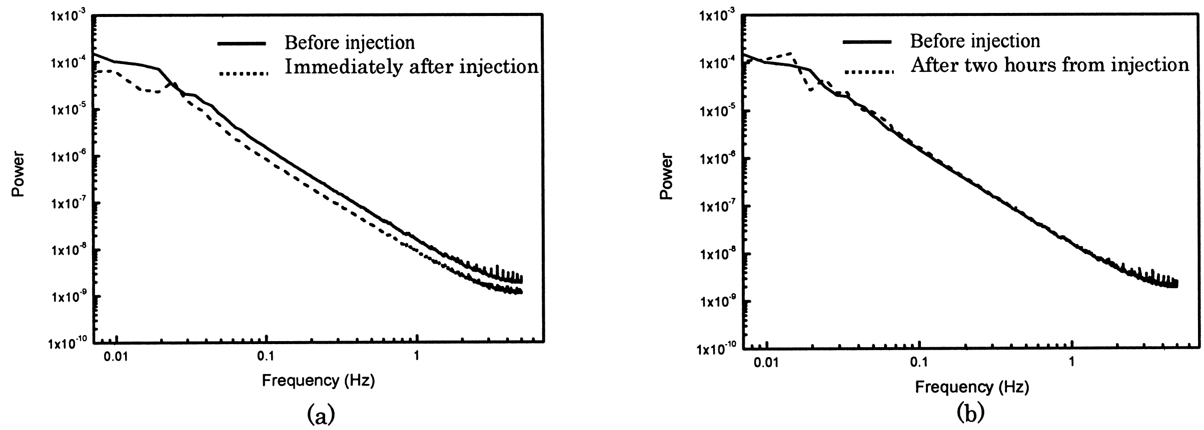


Fig. 7 Power spectra of bioelectrical potential of Schefflera under light illumination condition. (a) Before gas injection and immediately after gas injection and (b) before gas injection and after two hours from gas injection.

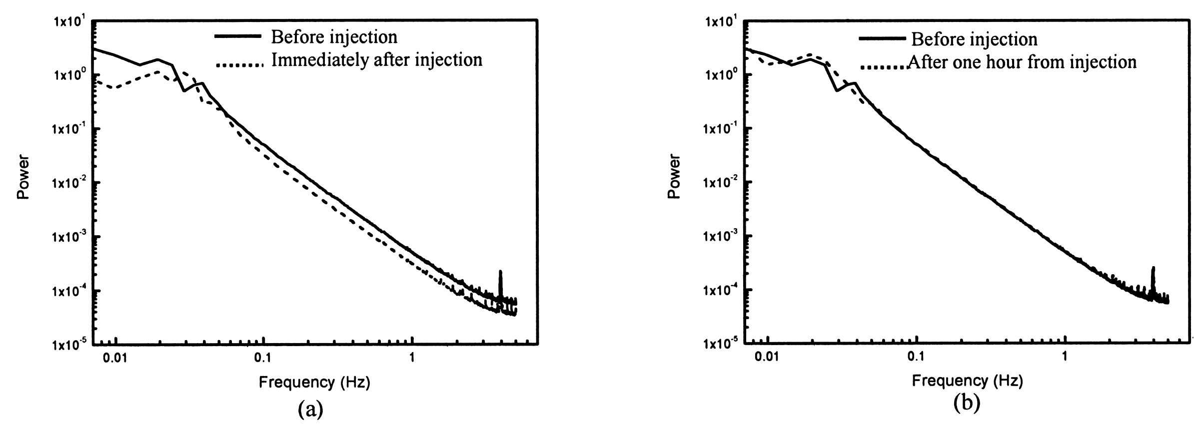


Fig. 8 Power spectra of bioelectrical potential of Boston fren under light illumination condition. (a) Before gas injection and immediately after gas injection. (b) Before gas injection and after one hour from gas injection.

3.3 Reconstruction of Orbits of Bioelectrical Potential in Higher Dimensional State Space

In the preceding section, we suggested that the spectral analysis of the bioelectrical potential has limitations in the evaluation of the air purification ability under the dark condition. To confirm this from the nonlinearity viewpoint, we investigated the nonlinear bioelectrical potential of Schefflera to reduce the amount of the pollutant gas using an analysis method from the nonlinear dynamical system theory. Let us describe the observed time series as $z(n)$, where n is a temporal index. If the time series $z(n)$ is a smooth output from a k-dimensional dynamical system f, the transformation to an m-dimensional vector by the following delay coordinate,

$$\{z(n), z(n+\tau), z(n+2\tau), \cdots, z(n+(m-1)\tau)\} \quad (1)$$

could reconstruct the topological and differential structures of the original dynamical system f with a sufficiently large dimension m and a delay value τ. Namely, embedding theorem [10] guarantees that the adove transformation is due to embedding.

In the case of applying the above procedure, it is often sufficient to set the value m to be not so large. Thus, we only use the 3-dimensional delay coordinate for transforming the observed bioelectrical potential for visualization.

Figure 9 (a) shows examples of a reconstructed 3-dimensional orbit of the bioelectrical potential of Schefflera under the dark condition before the gas injection. It seems that the time delay vector traces a certain regular orbit to form the specific attractor. On the contrary, the reconstructed orbit of the same plant under the dark condition after the gas injection had different traces as shown in Fig. 9(b). Next, Fig. 9(c) shows an orbit before the gas injection under the light illumination condition. We found that the orbit at the lower part is a little deformed. Figure 9(d) shows a reconstructed orbit after the gas injection under the light illumination condition. It is obvious that the gas injection had considerable influence on the shape of the orbit. For example, after the gas injection, the deformed orbit observed in Fig. 9(c) at the lower part disappeared.

These characteristics concerned in the reconstructed

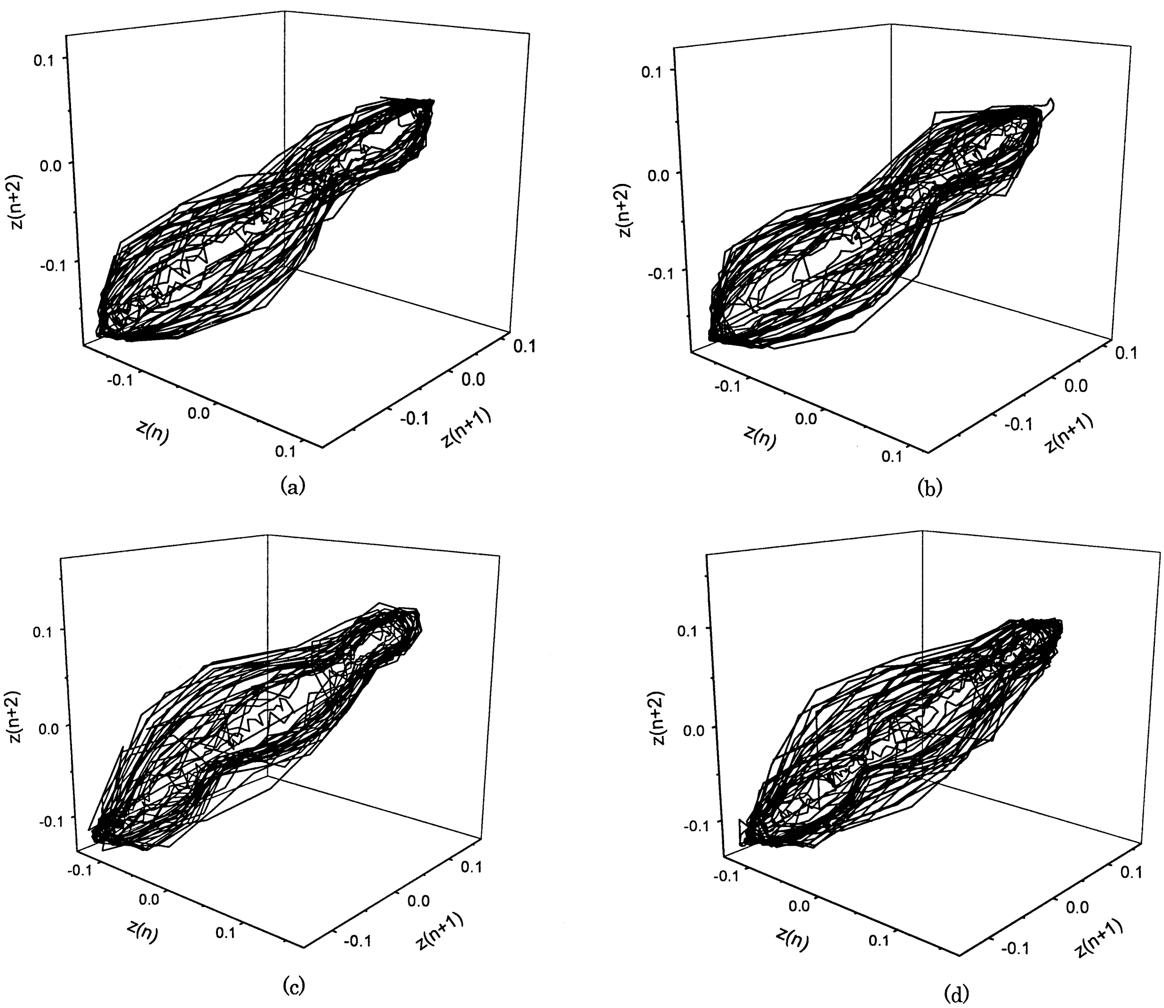


Fig. 9 Reconstructed orbits of bioelectrical potential of Schefflera. (a) Under dark condition before gas injection, (b) under dark condition after gas injection, (c) under light illumination condition before gas injection and (d) under light illumination condition after gas injection.

state space can be further extended to more quantitative characterization with the theory of the deterministic nonlinear prediction. Preliminary discussions on these results indicate that the bioelectrical potential could have one of the important properties of deterministic chaos; long-term unpredictability and short-term predictability.

4. Conclusions

We investigated the air purification ability of plants by the measurement of AC bioelectrical potential. First, we confirmed that Schefflera and Boston fern had high abilities to remove the pollutant gas and the abilities were influenced by the light illumination condition.

Next, we showed that the power spectra of the time series obtained from the plants shifted to a lower level after the gas injection over all frequencies. This shift of the power level recovered gradually corresponding to the gas reduction procedure and almost reached the initial level after a few hours. The results also suggested that the AC bioelectrical potential has a $1/f^2$ characteristic. We also investigated the characteristic properties of the fluctuating behavior of the potential from the viewpoint of nonlinear dynamical systems. We transformed the time series into a higher dimensional state space by a delay coordinate, which is a common technique in the field of nonlinear time series analysis. The results show that the orbits in the delay coordinate had specific traces and changed with the gas injection.

Thus the measurement of bioelectrical potential could be a useful method of evaluating the air purification ability of plants.

It is very important to investigate the mechanism of the air purification process of plants for pollutant gas. In future work, we will clarify the mechanism of this ability.

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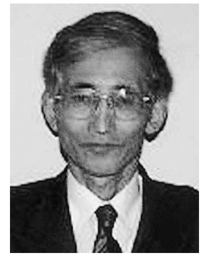

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