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RESEARCH ARTICLE

Automatic online testing methods of soil CO_2 concentration

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Abstract **An online extraction method for monitoring CO_2 concentration during soil respiration is described based on the assay of gas pump and gas extraction with a dynamic air chamber. Also, a study is done on the relationship between data collected from online CO_2 measurement and time, as well as the curve fitting. This method uses the optimization algorithm to extract the CO_2 concentration in the soil respiration chamber, and sets up a mathematical model for online soil CO_2 concentration extraction. It is verified that the extraction method is feasible with the automatic site detection. This method, which can reduce the volume of data redundancy and improve data reliability, has a high reference value for the similar characteristics of online data extraction, compared with the traditional CO_2 detection methods during soil respiration.**

Keywords deep soil respiration, online unattended monitoring, polynomial fitting, optimization

Introduction

Soil CO_2 respiration is the main method for the return of CO_2 to the atmosphere after being fixed by terrestrial plants, and its status determines the speed of soil carbon turnover. Small changes in soil respiration will have a significant impact on the global carbon balance, and influence future changes in atmospheric CO_2 concentration (Baoyu et al., 2009). With the continuous increase of global warming, global land use and the method of cover evolution, it will be possible to some extent to reduce terrestrial ecosystem carbon absorption capacity (O'Neill et al., 2002). Soil respiration has an extremely important influence on the growth of plants. With the use of appropriate terrestrial ecosystem carbon management policies and implementation of appropriate technology by exchange, it will be possible to increase the terrestrial ecosystem carbon absorption capacity (Zhou et al., 2005). Therefore, different ecosystems, soil and atmospheric carbon gas exchange processes of influencing factors have attracted great attention from the academe (Bo and Pernille, 2005).

Presently, the methods of soil respiration measurement mainly include indirect and direct measurement methods (Wang and Wang, 2003). The dynamic chamber method is sensitive to air pressure difference inside and outside, but it can reflect the true rate of soil respiration (O'Neill et al., 2002). Soil respiration measurement instruments have now been commercialized, such as the SRS-2000 (portable soil respiration measuring system), SR1LP (soil respiration measurement system) and LI-8150 (the United States multi-extension soil respiration systems) (Qiguo, 2008). However, the general disadvantage is weak real-time processing of data, no dynamic analysis process, and off-line data analysis (Peng et al., 2002). In the analysis of soil respiration measurement instruments based on the combination of large-scale monitoring of the actual requirements, according to the pump gas extraction chamber assay dynamic thinking, an online extraction method for CO_2 concentration was developed, with which the real-time analysis of sensor data was used to find the actual concentration of carbon dioxide in soil value for multi-point auto-measurement and the design of an online soil respiration monitoring system for different types of soil respiration measurement.

Materials and methods

Experimental materials

The system uses a carbon dioxide sensor for real-time detection of soil carbon dioxide concentration, vacuum solenoid valve and gas pump to pump gas into a vacuum chamber. The overall structure is shown in Fig. 1.

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Methods

Variation

CO_2 absorbs the infrared band for the selective absorption of specific wavelengths (4.26) depending on the concentration of the tested materials. The system uses single-wavelength analysis of non-dispersive infrared measurements and then draws CO_2 infrared absorption spectrum concentrations. Finally, the system extracts characteristic peaks to realize the CO_2 concentration measurement. The relationship between carbon dioxide concentration and time curve measured by online switching measurement is shown in Fig. 2, with the measurement data extraction by removing the residual gas pipeline.

Extraction

By doing multiple single-point CO_2 concentration detection experiments, the relationships between carbon dioxide data and time in soil-line automatic measurements are shown in Figs. 3 and 4 in dotted lines.

After data analysis, the system needs pre-5S delay (just doing gas extraction without taking the data for analysis) for the previous monitoring of carbon dioxide concentration, because of the residual gas effect in the total airway and fittings in the gas extraction process. The system uses a delay sampling method to eliminate part of the residual gas in the whole airway and fittings.

Repeated measurement data through analysis shows that on reaching the maximum value, the data show a slow decreasing trend. Compared with the known data using the conventional diffusion method, the maximum value is the goal of CO_2 concentration, the reason for the decline in CO_2 concentration in the gas chamber is that the air goes through the surface soil and traces into the chamber during extraction.

The system uses the curve fitting method of data preprocessing to avoid causing instability by the raw data directly. Considering the reliability of test data, real-time detection, and the curve characteristics, the system uses polynomial curve fitting method for data preprocessing.

By the repeated measurements of the initial detection points and middle detection points and using the second, third, fourth and fifth polynomial curve fitting methods for analysis, it can improve data stability, accuracy, reliability and real-time monitoring using four polynomial fitting methods. Fitting curves are shown in Figs. 3 and 4 in solid lines. The formula to achieve the process is as follows:

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4.$$

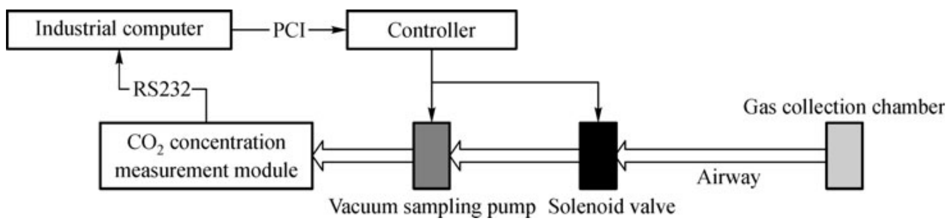

Figure 1 Structural diagram of the system.

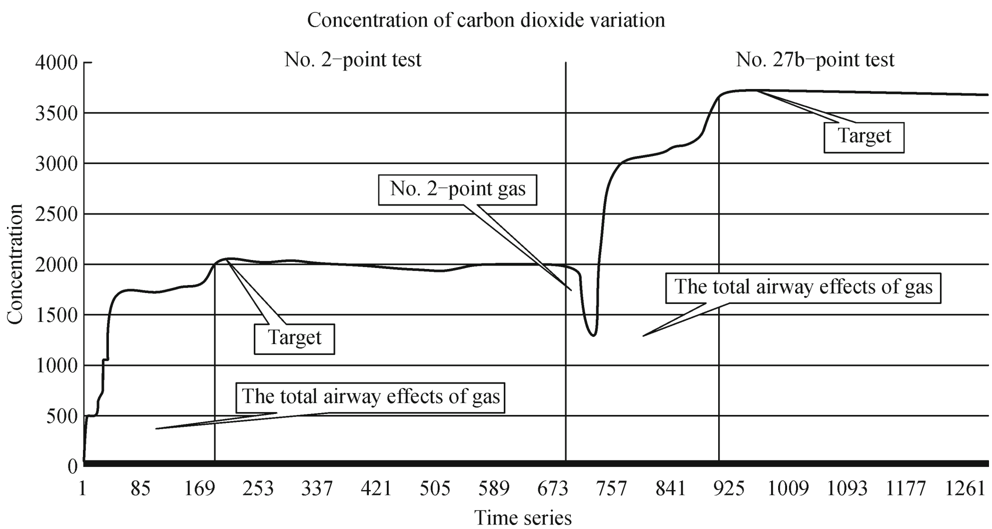

Figure 2 Test pattern of CO_2 concentration.

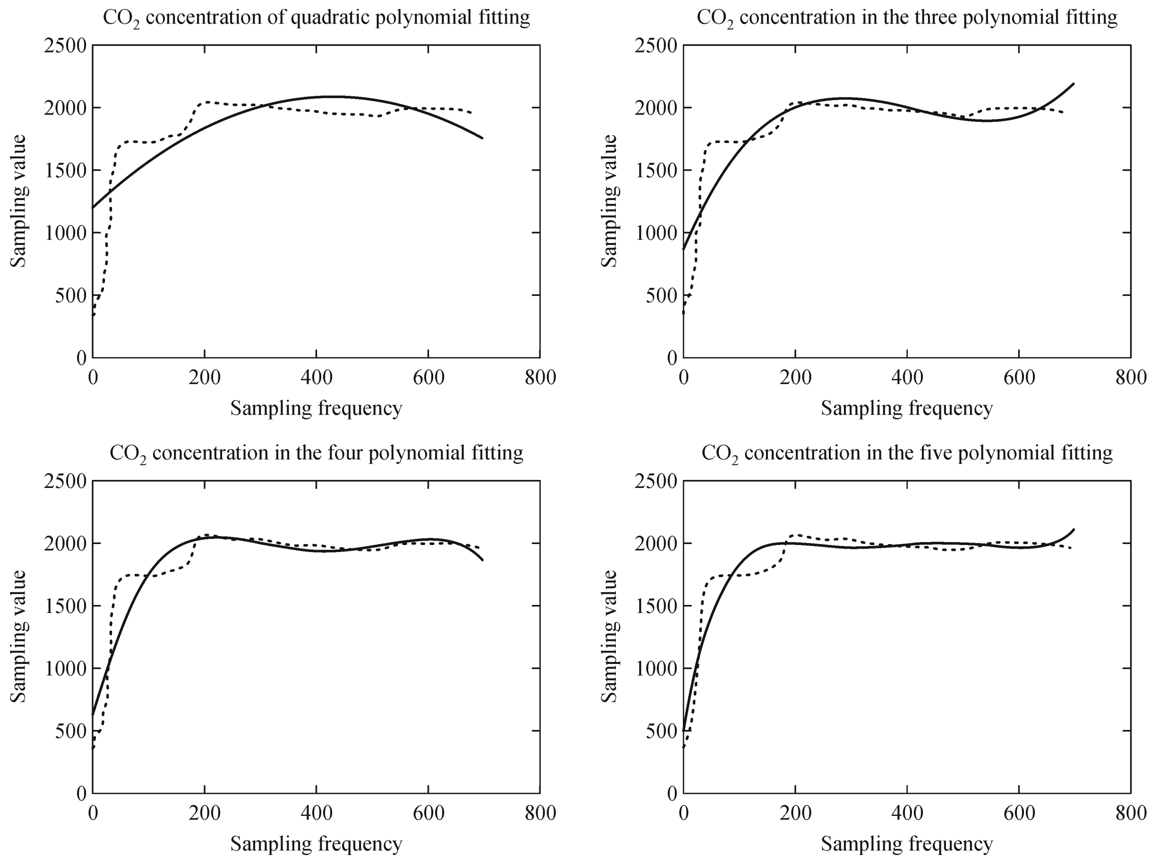

Figure 3 CO_2 concentration in the starting point detection.

The coefficients are calculated as follows:

$$a_0 = \frac{(x_2x_3x_4x_5)y_1}{(x_2-x_1)(x_4-x_1)(x_3-x_1)(x_5-x_1)} + \frac{(x_1x_3x_4x_5)y_2}{(x_2-x_1)(x_3-x_2)(x_4-x_2)(x_5-x_2)} - \frac{(x_1x_2x_4x_5)y_3}{(x_3-x_2)(x_4-x_3)(x_3-x_1)(x_5-x_3)} + \frac{(x_1x_2x_3x_5)y_4}{(x_4-x_3)(x_4-x_1)(x_4-x_2)(x_5-x_4)} - \frac{(x_1x_2x_3x_4)y_5}{(x_5-x_3)(x_5-x_1)(x_5-x_2)(x_5-x_4)}$$

$$a_1 = -\frac{(x_2x_3x_4+x_2x_3x_5+x_2x_4x_5+x_3x_4x_5)y_1}{(x_2-x_1)(x_4-x_1)(x_3-x_1)(x_5-x_1)} + \frac{(x_1x_3x_4+x_1x_4x_5+x_1x_3x_5+x_3x_4x_5)y_2}{(x_2-x_1)(x_3-x_2)(x_4-x_2)(x_5-x_2)} - \frac{(x_1x_2x_4+x_1x_2x_5+x_1x_4x_5+x_2x_4x_5)y_3}{(x_3-x_2)(x_4-x_3)(x_3-x_1)(x_5-x_3)} + \frac{(x_1x_2x_3+x_1x_2x_5+x_1x_3x_5+x_2x_3x_5)y_4}{(x_4-x_3)(x_4-x_1)(x_4-x_2)(x_5-x_4)} - \frac{(x_1x_2x_3+x_1x_2x_4+x_2x_3x_4+x_1x_3x_4)y_5}{(x_5-x_3)(x_5-x_1)(x_5-x_2)(x_5-x_4)}$$

$$a_2 = \frac{(x_2x_3+x_2x_4+x_3x_4+x_2x_5+x_3x_5+x_4x_5)y_1}{(x_2-x_1)(x_4-x_1)(x_3-x_1)(x_5-x_1)} - \frac{(x_1x_3+x_3x_4+x_4x_1+x_1x_5+x_3x_5+x_4x_5)y_2}{(x_2-x_1)(x_3-x_2)(x_4-x_2)(x_5-x_2)} + \frac{(x_1x_2+x_2x_4+x_4x_1+x_1x_5+x_2x_5+x_4x_5)y_3}{(x_3-x_2)(x_4-x_3)(x_3-x_1)(x_5-x_3)} - \frac{(x_1x_2+x_2x_3+x_3x_1+x_1x_5+x_2x_5+x_3x_5)y_4}{(x_4-x_3)(x_4-x_1)(x_4-x_2)(x_5-x_4)} + \frac{(x_1x_2+x_2x_3+x_3x_1+x_1x_4+x_2x_4+x_3x_4)y_5}{(x_5-x_3)(x_5-x_1)(x_5-x_2)(x_5-x_4)}$$

$$a_3 = -\frac{(x_2+x_3+x_4+x_5)y_1}{(x_2-x_1)(x_4-x_1)(x_3-x_1)(x_5-x_1)} + \frac{(x_1+x_3+x_4+x_5)y_2}{(x_2-x_1)(x_3-x_2)(x_4-x_2)(x_5-x_2)} - \frac{(x_1+x_2+x_4+x_5)y_3}{(x_3-x_2)(x_4-x_3)(x_3-x_1)(x_5-x_3)} + \frac{(x_1+x_2+x_3+x_5)y_4}{(x_4-x_3)(x_4-x_1)(x_4-x_2)(x_5-x_4)} - \frac{(x_1+x_2+x_3+x_4)y_5}{(x_5-x_3)(x_5-x_4)(x_5-x_1)(x_5-x_2)}$$

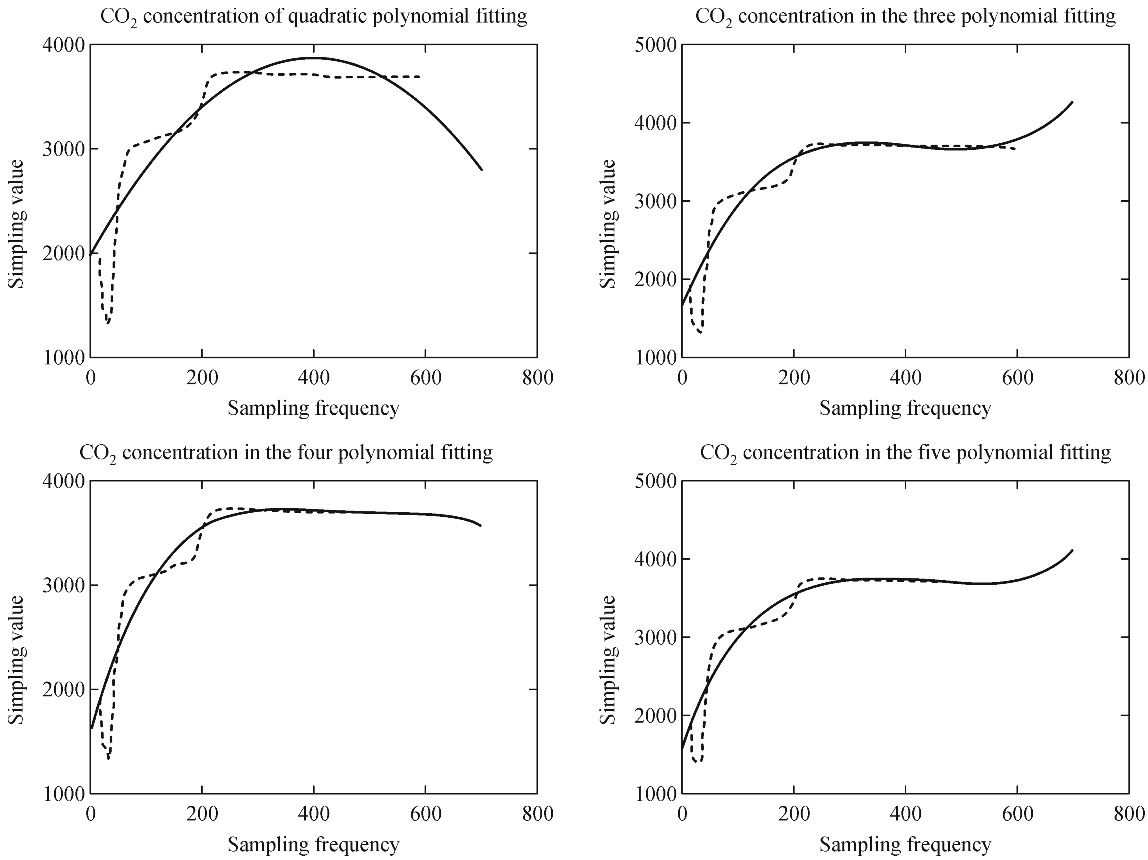

Figure 4 CO_2 concentration in the middle of measurement points detection.

$$a_4 = \frac{y_1}{(x_2-x_1)(x_4-x_1)(x_3-x_1)(x_5-x_1)} - \frac{y_2}{(x_2-x_1)(x_3-x_2)(x_4-x_2)(x_5-x_2)} - \frac{y_3}{(x_3-x_2)(x_4-x_3)(x_3-x_1)(x_5-x_3)} - \frac{y_4}{(x_4-x_3)(x_4-x_1)(x_4-x_2)(x_5-x_4)} - \frac{y_5}{(x_5-x_3)(x_5-x_1)(x_5-x_2)(x_5-x_4)}$$

Many experiments comparing the known data using the conventional diffusion method show that the maximum value of CO_2 concentration occurs within 700 data sampling targets. In the detection process, the amount of data has a great influence on real time data acquisition. Through the experiment analysis the data on soil carbon dioxide concentration can be reliably detected to achieve the actual value of the extract within 300 numbers measurement by carbon dioxide sensors LI-840.

The goal of this study was to gain the overall extreme for all the data, using the fastest one-dimensional function of the derivative method to find the entire local maximum, and then select the largest extreme value from them. The simulation diagram is shown in Fig. 5.

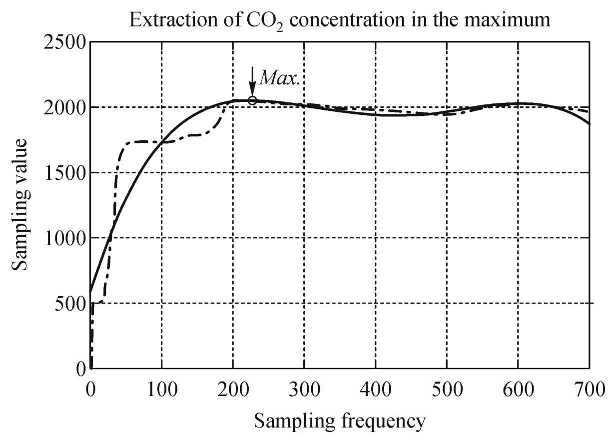

Figure 5 CO_2 extraction of CO_2 concentration in the maximum.

Results

Soil multi-point line monitoring of deep breathing test was conducted at the Rice Research Institute (31°41′27″N, 103°44′17″E) in March, 2010. In the on-site monitoring process, the system achieved unattended automatic monitoring by setting the timer. The experimental data of the online multi-point monitoring system for soil deep breathing monitoring and traditional static chamber method at the same location and same depth of soil respiration monitoring are shown in Fig. 6.

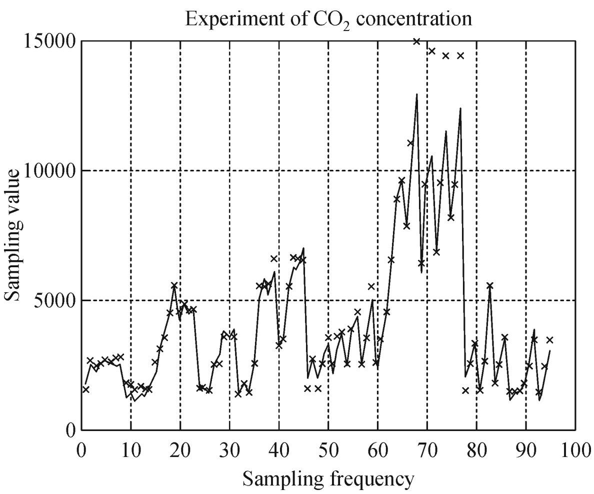

Figure 6 Measurement chart. × is the concentration of carbon dioxide data measured by the static chamber method, while the solid line is the data monitoring by the automatic monitoring system.

The system ran well in the experiment and the single-point measurement time (measured from request to completion) was 8–12 s. The various data were measured at the same time when data analysis was on. The reason why different points had different concentrations of carbon dioxide in the experiment was that different microorganisms were added to the soil in different monitoring points. The data had relatively large fluctuations in the static chamber method during the operation compared with the automatic monitoring system. The results showed that the automatic extraction method for the multi-threaded multi-point soil respiration online monitoring system was fully capable of achieving the online soil respiration multi-point monitoring requirements.

Discussion

Through online field monitoring of the soil respiration method, the sensor technology, field technology, infrared technology and soil science, the development of a multi-point soil respiration line monitoring system was completed. Based on indoor gas pump extraction under dynamic chamber test, and in-line measurement of carbon dioxide data collected on the basis of curve fitting, the establishment of CO_2 concentration in the soil line extraction model was conducted. Compared with the CO_2 concentration in soil respiration measured by the traditional testing method, the proposed method reduces the data redundancy and improves data reliability. Also, data for the online extraction of similar characteristics have a high reference value. The system operation shows its stability, reliability and real time for monitoring. The more traditional monitoring methods, the better reflection of the ability of soil respiration. Therefore, this system is more suitable for measuring many types of soil respiration under the status of long real-time measurement and monitoring. Extraction of CO_2 concentration of soil respiration is very important both in theoretical research and practice.

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