

Continual observation on crop leaf area index using wireless sensors network

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Abstract. Crop structural parameter, i.e. leaf area index(LAI), is the main factor that can effect the solar energy re-assignment in the canopy. An automatic measuring system which is designed on the basis of wireless sensors network(WSN) is present in this paper. The system is comprised of two types of node. One is the measurement nodes which measured solar irradiance and were deployed beneath and above the canopy respectively, and another is a sink node which was used to collect data from the other measurement nodes. The measurement nodes also have ability to repeater data from one node to another and finally transfer signal to the sink node. Then the collected data of sink node are transferred to the data center through GPRS network. Using the field data collected by WSN, canopy structural parameters can be calculated using the direct transmittance which is the ratio of sun radiation captured by the measurement node beneath and above the canopy on different sun altitude angles. The proposed WSN measurement systems which is consisted of about 45 measurement node was deployed in the Heihe watershed to continually observe the crop canopy structural parameters from 25 June to 24 August 2012. To validate the performance of the WSN measured crop structural parameters, the LAI values were also measured by LAI2000. The field preliminary validation results show that the designed system can capture the varies of solar direct canopy transmittance on different time in a day, which is the basis to calculate the target canopy structural parameters. The validation results reveal that the measured LAI values derived from our propose measurement system have acceptable correlation coefficient(R^2 from 0.27 to 0.96 and averaged value 0.42) with those derived from LAI2000. So it is a promising way in the agriculture application to utilize the proposed system and thus will be an efficient way to measure the crop structural parameters in the large spatial region and on the long time series.

1. Introduction

Measurement methods for ground validation of LAI products can be classified into two types: the direct and the indirect method[1]. The direct method is used to calculate the leaf area index through destructive sampling, which is then converted to LAI. Though, it is the most reliable way to obtain the ground truth of LAI, due to its limitation on labor-intensive, the direct method is only be useful to obtain the reference value of the ground LAI, which will be used to calibrate other indirect measuring instruments. As a result, in the practical work, remote sensing LAI products validation experiment relies largely on indirect measurement method which uses optical instruments to obtain the ground LAI.

Despite the fact that the measurement mode of instruments which relies on a person who walks inside the experimental quadrates with devices in his hands to obtain the measured values of multiple quadrates improve the efficiency in the measurement of LAI to a certain degree, when conducting



observations in large spaces, this mode requires massive consumption of labor and takes a long period to take samples[2]. Constrained by the satellite re-visit time, ground measurements are generally completed within several days before or after the satellite transits in the ground synchronous experiments or quasi-synchronous experiments[3]. For the validation of LAI products at 1km resolution similar to MODIS, it is assumed that ground experiments require ground-base observation data with 2*2 MODIS pixels. It is always difficult to obtain the leaf area index data within such a large space in a short period of time.

Ground validation experiments on remote sensing of surface parameters are in urgent demand for low-cost automatic LAI measurement instruments for that applies to large spaces. Besides, the system is required to be energy saving, which makes it possible to carry out simultaneous observation of a great number of measured points in space and ensure the power supply to provide energy for the continuous observation in the time series. We measured the LAI by calculating the direct light transmittance, on which basis we have developed a low-cost LAI network measurement system, the LAI_{Net}, based on wireless sensor network technology. This paper further validates the performance of the LAI_{Net} from the aspects of multi-point measurements in space and continuous measurements in time series.

This paper is aimed to:

- develop a wireless sensor network system for the automatic measurement of LAI applicable to the validation of remote sensing products.
- validate the measurement performance of the new canopy structure parameters measuring system and conduct a comparative analysis with commonly used LAI measurement instruments.

2. Experimental Design

The work on field experiments in this paper is part of the joint experiment of integrated remote sensing observations of ecology-hydrological processes of Heihe watershed. The experiments area is in the middle valley of the Heihe River[4], which is located in Yingke/Daman irrigation districts (longitude: 100°40'E, latitude: 38°80'N). The observation started from June 2012 to August 2012. Corn, a typical row crop, was selected as the object of observation, with the plant spacing of 10-20cm and row spacing of 50-70cm.

The LAI_{Net} is a device for automatically obtaining multi-angle transmittance of vegetation canopies based on the wireless sensor network technology. This wireless sensor network system consists of three types of nodes: nodes above canopies that receive total downward solar radiation, nodes under canopies that receive radiation penetrating vegetation, and sink nodes used to collect data and transmit data to the remote data server via GPRS network. For detailed information about the system architecture, please see Yonghua[5]. We deployed nine sink nodes of LAI_{Net} within the range of 4km*4km. Each sink node is connected with 3-9 measurement nodes, with a total of 42 measurement nodes under canopies and 3 nodes above canopies. The node deployment diagram of instruments in the experiment area is shown in figure 1.

The sink nodes are powered by solar energy with the antenna system fixed on a 2.5m high support, which ensures that communication signals are not sheltered by corn canopies. 3 nodes above canopies and their corresponding convergent antennas are deployed on the upper side of the support so that the nodes above canopies are in open spaces and free from being sheltered by other objects. The nodes under canopies are powered by rechargeable lithium batteries and deployed in the direction perpendicular to corn ridges in the way of upward observation. Data communications are available between measurement nodes and sink nodes in a direct or multi-hop way.

In the experiment area, we use LAI 2000 to measure the vegetation LAI in places surrounding some nodes so as to obtain the validation data of the measurement results of the LAI_{Net}. The LAI2000 measurement site is selected basing on the principle that the growth of the corn at two measured points is basically the same through visual judgment.

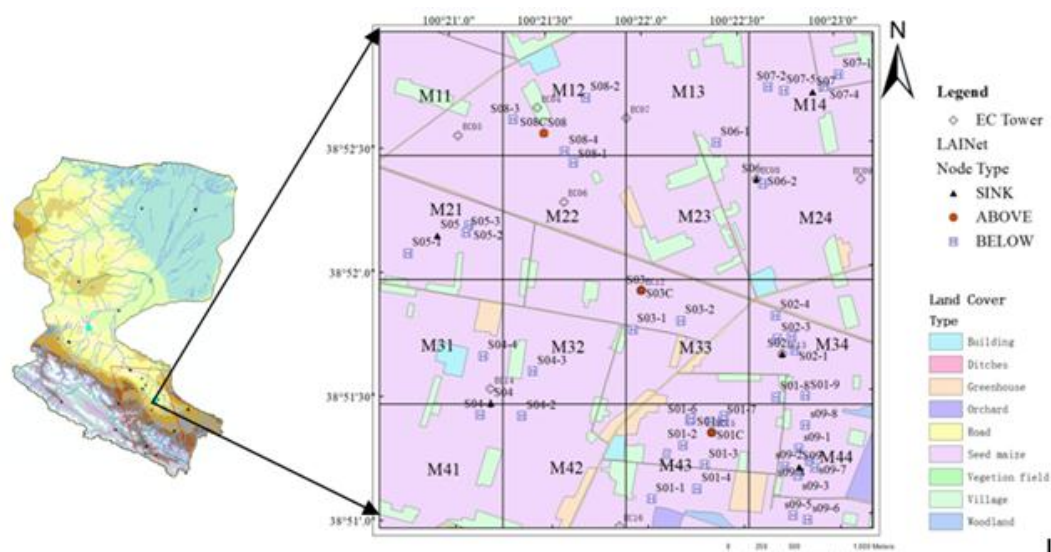


Figure 1. Node deployment diagram of instruments in the experiment area.



Figure 2. The experimental instruments.

3. Results and Discussion

3.1. Comparison of the measured value between LAINet and LAI 2000

Due to battery or communication failures during the observation using LAINet instruments and the influences caused by cloudy and rainy days, it is impossible to get corresponding measured values of LAINet at each measuring time of LAI 2000. Consequently, the number of data pairs of each site that can be compared is not the same. In order to compare the results of two different measurement

instruments using field measured data, we chose data from two adjacent instruments (within 100 meters) which have 1 or 2 days' difference in the measuring time. Figure 3 shows the results of the comparison between the measured values of LAINet and LAI 2000.

It can be seen from Figure 3 that, of the results of the comparison made by site, the coefficient of determination between the two ranges from 0.28 to 0.97 and the comparison results of all measured data R^2 is 0.42. This indicates that the relevance between the data measured by the two instruments vary greatly. The most relevant data appear at site ECO6 and the data is collected from June 25 (DOY=177) to August 11 (DOY=224). The LAI ranges from 1.6 to 3.4. The least relevant data appear at site EC14. At this site, the highest deviation between the two appears when the LAI value is around 1.5 or higher than 3.0.

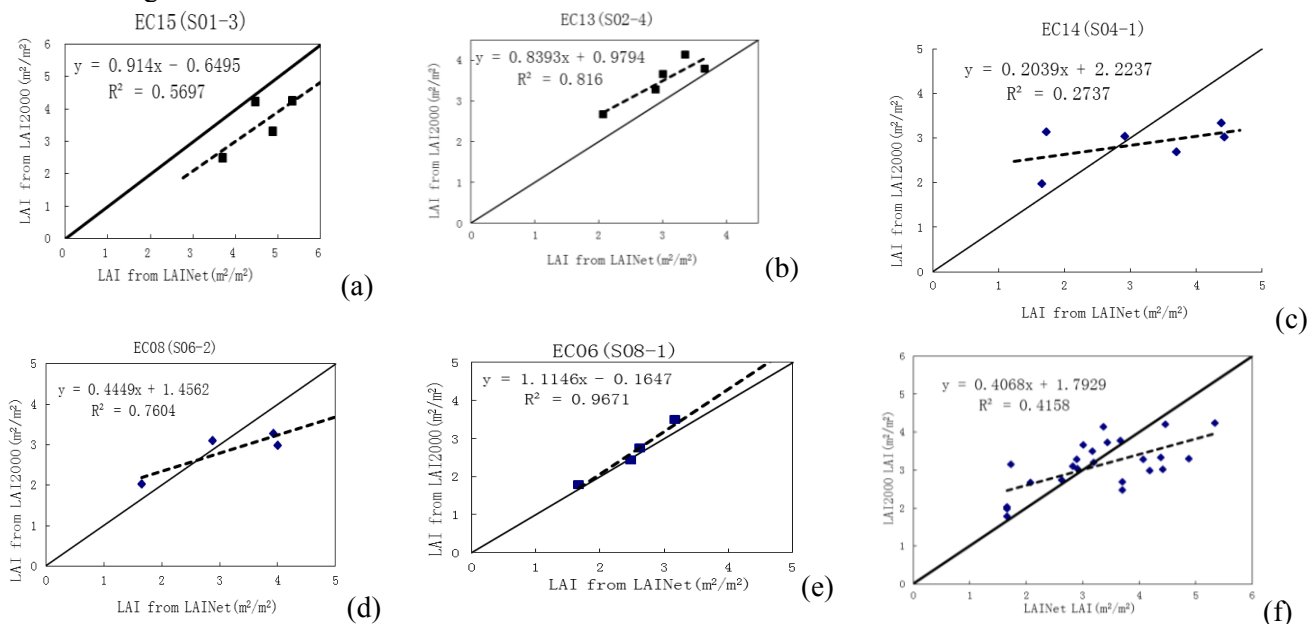


Figure 3. The scatter plot of the measured LAI values of LAINet and LAI 2000.

The abscissa represents the observed values of LAINet and the ordinate represents the measured values of LAI 2000. (a)-(e) are point-by-point comparisons according to the measured points. The titles of the figures show the numbers of eddy correlation matrices where test points are located and the numbers of the nodes measured by LAINet. (f) shows the results of comprehensive comparison of all points. The solid lines in the figure are 1:1, the dotted lines are the regression lines of scatter plots. The regression equations and coefficients of determination (R^2) are shown at the upper left corners of the plots.

In general, with LAI=3.5 as the dividing point, when LAI<3.5, the estimates of LAI 2000 are higher than those of LAINet; when LAI>3.5, the observed values of LAI 2000 are lower than those of LAINet. Unfortunately, this study did not get the LAI destructive measured value of corn. Therefore, we can't determine which of the two instruments is more accurate in a direct way. However, according to the literatures, the research results of many researchers have indicated that the estimates of LAI 2000 are smaller than the true LAI values. In particular when the LAI is relatively large, the observed values of LAI 2000 are lower than its true values. After measuring and comparing the canopy LAI of broad-leaved forests and coniferous forests, Martens et al. found that LiCor light quantum instruments based on the direct light method have higher estimates than LAI 2000 based on the scattered light. Compared with the direct measurement method, the LiCor method of direct light has the best estimation accuracy. According to the measurement results of broad-leaved forests and coniferous forests, Mason et al. discovered that the ratio of the value obtained through direct measurement to that measured by LAI 2000 is about 1.5. We get similar findings through our measurement results. When

the LAI is relatively large (higher than 3.5), the average ratio of the observed value of LAINet with the direct light principle to that of LAI2000 is about 1.3. This result may indicate that the measured value of LAINet may be closer to the true LAI value of crops. However, this conclusion needs to be supported by the ground true measured values.

3.2. Analysis of time series

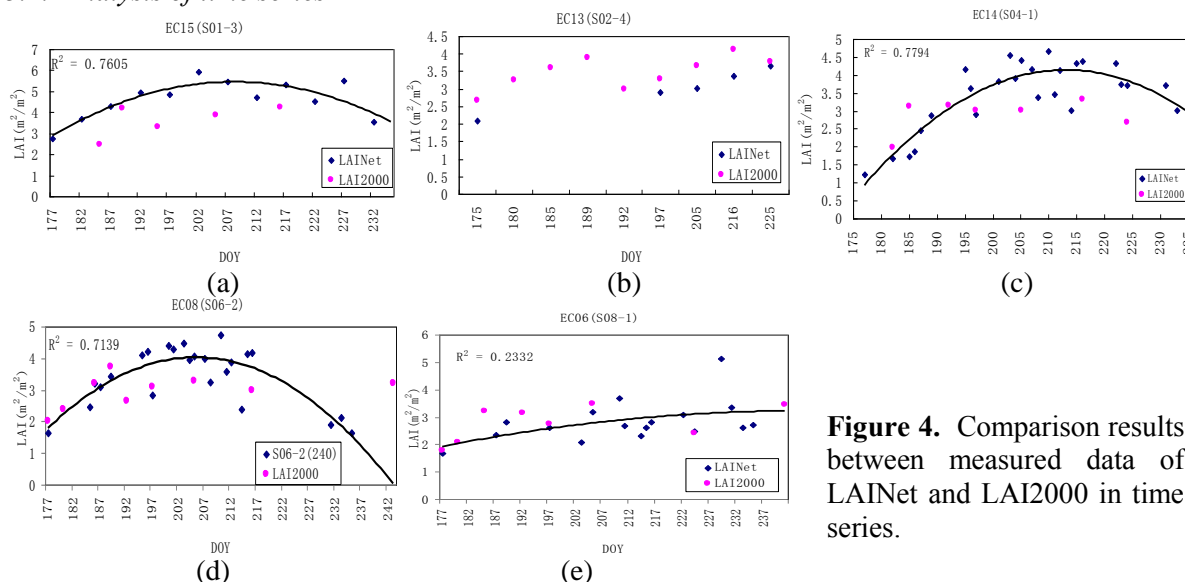


Figure 4. Comparison results between measured data of LAINet and LAI2000 in time series.

Sites (a)-(e) corresponds to (a)-(e) in figure 3 respectively. The solid lines in (a), (c)-(e) are quadratic curves fitted from the observed values of LAINet. The coefficients of determination of the fitting (R^2) are indicated at the upper left corners. Due to a small amount of data which were obtained at long intervals, we didn't do fitting of (b).

It can be seen from figure 4 that observed data of LAINet in sites other than EC13 (S02-4), in which continuous observation in terms of time was not formed, can basically depict the dynamic characteristics of changes in growth of corn in the Heihe experiment area. Curves of dynamic changes of the LAI fitted in the sites EC15 (S01-3), EC14 (S04-1) and EC08(S06-2) show a common characteristic. Namely, in Heihe area at about DOY=207-210, the LAI of corn in this area is the biggest at the growth stage and then starts to decrease. The results agree with the data that have been observed via satellite for years. Although the fitting result in time series at EC06 (S08-1) is not as good as that of the above three nodes, it can be seen from measured data that in this site and before and after DOY=207-212, the measured value of LAI is relatively high. But during the observation dates higher than DOY=212, especially around DOY=232, the measured value of LAINet varies greatly and the observed value of LAINet can capture the reduction of LAI.

4. Conclusions

An automatic measurement system of vegetation leaf area index based on the wireless sensor network technology has been implemented in this paper. With corn in the Heihe River as the research object, continuous observation in time series were conducted. The LAI values in time series were obtained and compared with MODIS products.

The wireless sensor network technology provides collection and remote transmission of data. This, on the one hand, makes data acquisition more automatic. On the other hand, operators are not required to enter the experiment area, which reduces disturbances in the growth of vegetation caused by human activities. The LAI measurement scheme proposed in this paper is applicable to the measurement of vegetation canopy structure parameters in long time-series on regional scale. It possesses good

prospects for the application in supporting the ground validation tests of remote sensing of surface parameters.

By comparison, we have found that the measured value of LAINet may be more accurate than that of LAI 2000, especially when the LAI is higher than 3.5. Through comparison between LAINet and LAI 2000 in the research area, the correlation coefficient (R) between the observed value of LAINet and that of LAI2000 ranges from 0.53 to 0.98. In general, when $LAI > 3.5$, the observed value of LAI 2000 changes dynamically over a smaller range and can't fully reflect the dynamic changes of the LAI. As far as the average value of twenty two observed data is concerned, the observed value of LAINet is higher than that of LAI 2000 with the ratio of about 1.3. The comparison results between the measured values and the true values of LAI 2000 in literatures show that when $LAI > 3.0$, LAI2000 will of values. It is also suggested that we need to deploy observed nodes of LAINet more carefully in the underestimate the true values of the LAI, with the ratio of the true values and measured values being about 1.5. This conclusion basically coincides with the experiment data in this paper.

As discussed above, another advantage of LAINet lies in the ability to provide dynamic observation of vegetation growth. The time series observation results of the LAI have indicated that the observed data of LAINet can properly describe the stage at which corn in the Heihe area grows and the stage at which corn stops growing as well as fading nodes. The date on which the LAI reaches its maximum is basically consistent with the data observed via satellite for years.

We made a multipoint average of the observed values of LAINet and compared with satellite data products and found that LAINet data and MODIS LAI products show similar laws in terms of time trend and that LAINet data are higher than MODIS LAI. The differences in the footprint of observed objects, surface consistence and time resolution of observations can explain the inconsistency in terms future so that the true situation of surface cover can be adequately reflected.

The presence of scattered light in the air has a significant impact on the observed values of LAINet. Currently, many instruments or means of observation have been used to obtain the proportion of scattered light. In the future, we are considering obtaining the proportions of scattered light corresponding to different times to increase the precision of the LAI inversion while LAINet is used for observation.

The low-power design is the basis to ensure the long service life of instruments. However, since the operational capability of the power supply system (lithium batteries) is affected by temperature, the expected working time is not achieved in the dry environment of the research area, which may result from the high temperature in corn canopies under high ambient temperature conditions. In the future, we will strive to future improve the performance of instruments and minimize manual maintenance, so that instruments can work continuously for a long time.

5. References

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