International Journal of Smart Home
Vol. 10, No. 8 (2016), pp. 1-10
http://dx.doi.org/10.14257/ijsh.2016.10.8.01

Research into Key Techniques of the Agricultural Greenhouse Monitoring System Based on Internet of Things

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Abstract

Intelligent greenhouse monitoring technique is an efficient agricultural control technique emerging recently. The threshold value control of the switching value is the most-adopted greenhouse control method. Due to unique characteristics of greenhouse, the existing monitoring style cannot meet the great demand of greenhouse for intensive monitoring. Concerning the monitoring demands of the greenhouse and based on the technique of Internet of Things, this paper introduces the multisensory fusion technique to the intelligent greenhouse monitoring system. The greenhouse environmental monitoring system based on ZigBee is built, and a two-layer fusion method of "sensor+aggregation node" is put forward. The Kalman filtering method and the weighted average method are employed to conduct sensor node fusion and aggregation node fusion, respectively. An experiment is carried out to verify the built model with the experimental results suggesting that the two-layer fusion method can improve the measurement accuracy and stability of the greenhouse environmental monitoring system.

***Keywords**: Internet of Things, wireless sensor networks, Kalman filtering, data fusion; greenhouse environmental monitoring*

1. Introduction

The greenhouse intelligent control technique is an efficient and intensive management technique rapidly developed in recent years. It is an automatic greenhouse environmental regulation and control system integrating computer control techniques, efficient sensor and so on. The prerequisite for the greenhouse control system is the accurate monitoring of the environmental factors. The complex greenhouse building structures results into the uneven distribution of various environmental parameters in the greenhouse. Therefore, it is necessary to collect multipoint parameters to comprehensive and correctly judge conditions within the greenhouse. The monitoring data of various sensors are the decision-making basis for the greenhouse intelligent control system. If data are not correct, greenhouse control will cause destructive damage. Thus, sensor technique is the prerequisite for the application of the greenhouse control technique.[1]

To use wireless sensor network technique to collect and manage greenhouse environmental parameters is a research focus of the current agricultural Internet of Things technique. Wireless sensor network sensor node devices feature a large number and a wide distribution scale. If sensor network nodes directly send data to network aggregation nodes, it will cause huge redundancy and data errors in aggregation nodes and influence

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ISSN: 1975-4094 IJSH

the aggregation nodes' efficient treatment of data. Moreover, the huge redundant data will also occupy a large number of network computing resources, bandwidth and energy during the transmission process.

The agricultural wireless sensor network system features a huge number of nodes and a long duration, thus resulting in a huge network data quantity. The increase of data quantity not only leads to the increase of the input of communications equipment and energy, but also increases the network energy consumption and shortens the network life cycle.

On the other hand, sensor parameters are highly related, periodic and similar to each other. The data redundancy is serious. Thus, it is necessary to analyze, gather, compress and extract characteristics of data within certain nodes or certain node groups, reduce data redundancy, and improve data accuracy and reliability under the prerequisite of meeting application demands.

Concerning the greenhouse Internet of Things architecture, this paper puts forward a two-layer fusion method of "node layer+aggregation layer" to conduct data fusion of the sensor. The fusion process is shown in Figure 1, To be specific, first, the value observed by the sensor at the same moment from the sensor nodes is fused in the node layer; second, the weighted average fusion algorithm is employed to conduct the heterogeneous multi-sensor fusion of the node fusion results in the aggregation layer so as to increase the data accuracy.

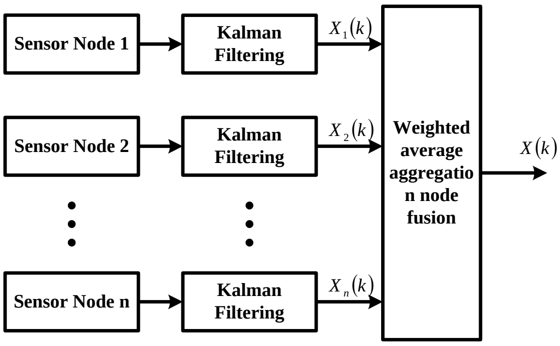


Figure 1. Two-Layer Fusion Process of the Wireless Observation and Control Network

2. Greenhouse Environmental Monitoring System Structure based on Internet of Things

2.1. System Structure

The agricultural greenhouse is to protect the agricultural production process through the artificially-built controllable environment. The emergence of Internet of Things has effectively achieved the real-time monitoring of the on-site environmental status of agricultural crops through cellphones or remote computers after network connection and utilization of various wireless sensors and network transmission devices distributed in the greenhouse to aggregate the air temperature, moisture, soil temperature, illuminance and other relevant parameters to central nodes.

Based on the ZigBee application technique and the application status of the greenhouse environment, this paper aims at solving problems, including inconvenient agricultural greenhouse cabling, difficult maintenance, and so on. The system structure diagram is shown in Figure 2, The system collects the environmental temperature, soil moisture, CO_2 concentration and illuminance, and connects with the environmental parameter collector through the ZigBee network. The environmental parameter collector is connected with Internet of Things to achieve fusion of the sensor layer and the transmission layer through the gateway. The gateway, on the one hand, connects with the environmental parameter collector and the meteorological collector through its serial port; on the other hand, connects with the interchanger through the Internet access to finish the conversion of the data from the serial port format to the Ethernet format. The gateway is embedded into the 3G module, which can be directly connected through the mobile Internet. Administration personnel can conduct system maintenance and daily management of the central control room. Terminal users can use cellphones, iPads, PCs and other methods to get access to the system's upper-layer services through various communications network access technique.

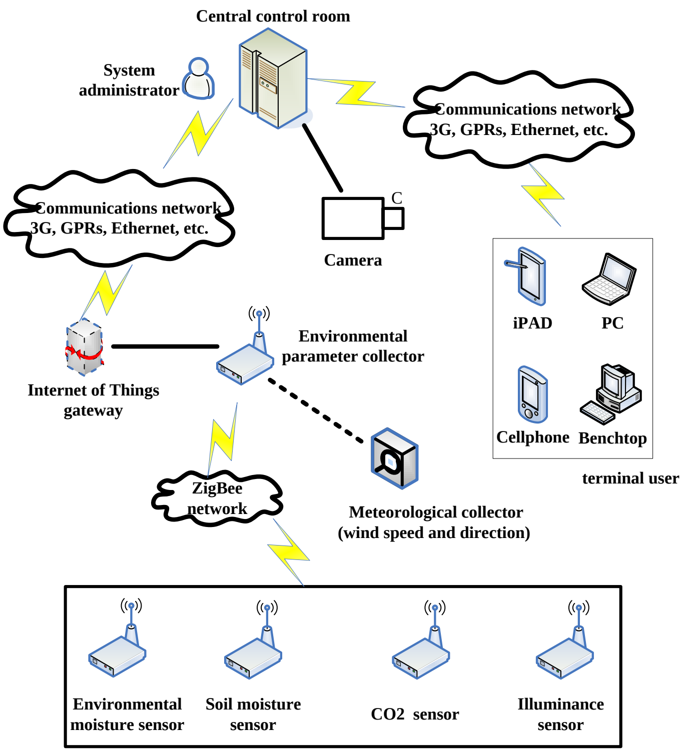


Figure 2. Greenhouse Environmental Structure Diagram based on Internet of Things

2.2. Aggregation Node Design of the Sensor

The sensor's aggregation node uses the full-featured ZigBee device, whose hardware circuit diagram is shown in Figure 3, The aggregation node module chooses CC2430 as the coordinator in the system. The following functions have been realized, including network formation and wireless transmission; calculation and verification; transmission of computer data and allocation of positioning nodes; use of the serial port and the computer communications; transmission of the computer data requests and allocation of the positioning node coordinates.

As the main control chip, CC2430 has few periphery expander circuits in terms of the number of devices. The representative periphery expander circuit is shown in Figure 3-2, RF input/output is the high-impedance and differential signal, and the optimal differential load of the RF port is $18j+115\Omega$. In order to realize the optimal performance, the design is realized through the low-cost inductance and capacitance. *C341*, *L341*, *L321* and *L331*, and a PCB are adopted to set RF input/output to be 50Ω. The antenna features the standard folded dipole, but the dipole has a virtual touch down point. Therefore, the bias will not influence the performance of the antenna.

The bias resistance includes *R221* and *R261*. The former, *R221*, is adopted as a precise bias resistance for 32768 crystal oscillator. In terms of crystal oscillator design, two crystal oscillators are adopted for selection. The external 32M crystal oscillator, XTAL1, has two load capacitors, namely *C191* and *C211*; XTAL2 is an optional 32.768KHz crystal oscillator.

In terms of the power design, the on-chip voltage stabilizer provides all pins with the voltage of 1.8V, and provides power supply within the system. *C241* and *C421* are employed to stabilize their operation; a series of resistors should meet the requirements of ESR. The power should have a proper decoupling function, which can be used to optimize the performance. The position and value of the decoupling capacitance and the filtration of power is of vital importance for an application to achieve the optimal performance.

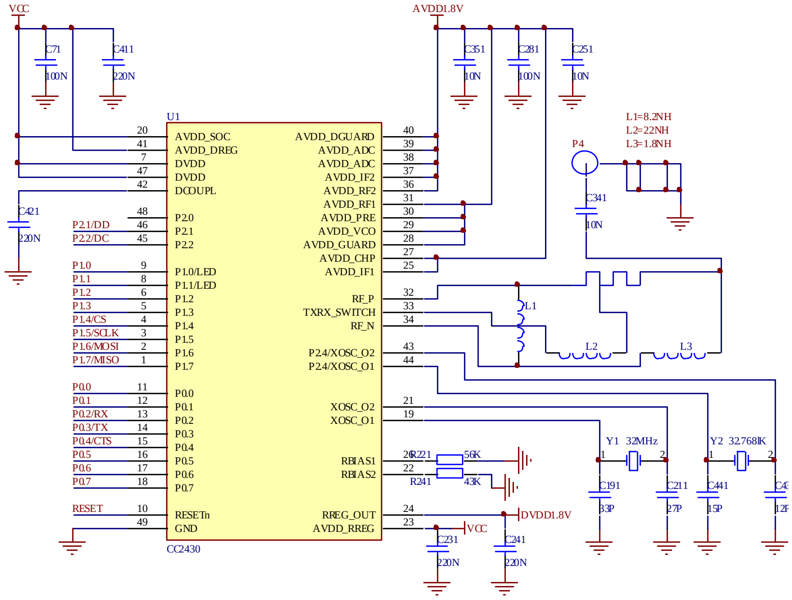


Figure 3. CC2430 Aggregation Node Electric Schematic Diagram

3. Two-Layer Sensor Data Fusion Algorithm

3.1. Node Data Fusion based on Kalman Filtering

3.1.1. Kalman Filtering: In order to improve the accuracy of the sensor to collect data and reduce the influence of the noise, the system adopts Kalman filtering. Kalman filtering consists of two steps, namely estimation and correction. Before the start, the current observed value and the previous estimated value are needed. At last, the current estimated value is obtained. Since Kalman filtering does not have a huge storage space and the data collected by the wireless sensor nodes are discrete in terms of time due to different geological positions, Kalman filtering is applicable to the wireless sensor network.

Before the use of the Kalman filtering algorithm, a system is introduced, and the system is a discrete process, which can be expressed by the linear stochastic differential equation as:

$$X(k) = AX(k-1)BU(k) + W(k) \tag{1}$$

Where, *U(k)*---The controlled quantity of the system at the k moment;

X(k)---The state variable of the system at the k moment;

A,B---The given system parameters.

Based on the value observed through the system, the following observation equation of the sensor is as below:

$$Z(k) = HX(k) + V(k) \tag{2}$$

Where, *U(k)*---The controlled quantity of the system at the k moment;

H---The given system parameters;

W(k), V(k)---The controlled quantity of the system at the k moment.

It is assumed that the system status is k. According to the system model and the former status of the system, the current status can be predicted:

$$X(k|k-1) = AX(k-1|k-1) + BU(k) \tag{3}$$

Where, $X(k|k-1)$---Results predicted by the former state prediction;

$AX(k-1|k-1)$---Optimal results of the former state.

$$P(k|k-1) = AP(k-1|k-1)A' + Q \tag{4}$$

Where, $P(k|k-1)$---The covariance of $X(k|k-1)$;

$P(k-1|k-1)$---The corresponding covariance;

A'---The transposed matrix of A;

Q---The covariance of the system process.

Eq. (3) and Eq. (4) are the predicted results of the current state. Based on the measured value of the current state, the optimal estimated value at the k moment can be obtained, which is $X(k|k)$:

$$X(k|k) = X(k|k-1) + K_g(k)(Z(k) - HX(k|k-1)) \tag{5}$$

Where, K_g ---Kalman gain;

$$K_g(k) = P(k|k-1)H' / (HP(k|k-1)H' + R) \tag{6}$$

After obtaining the optimal estimated value, X(k), under the k status, Eq. (7) is used to update the covariance of $X(k|k)$ at the moment of k so as to maintain the continuous operation of the Kalman filter until the end of the system.

$$P(k|k) = (I - K_g(k))HP(k|k-1) \tag{7}$$

Where, I stands for the matrix of "1." In terms of the single measurement of the single model, $I = 1$. The covariance, P, of $X(k|k)$ at the moment of k can be calculated based on Eq. (7). After that, Kalman filtering can be calculated through self-regression.

According to the above description, the agricultural greenhouse can be regarded as a system. Temperature is taken as an example. In terms of system modeling, the temperature of the greenhouse is assumed to be constant. In other words, the temperature of the former hour and the current temperature are the same. $A=1$; controlled variable, $U(k)=0$; $H=1$.

3.1.2 Sensor Data Processing

The data results collected by the sensor are not exactly accurate. If two data are close to each other, it suggests the mutual trust degree between the two data is high, and the data fusion between the two can be realized. In terms of the same environmental parameter obtained through the multi-sensor observation, the higher authenticity of the mutual trust degree between Data i observed by the i sensor and Data x_j observed by the j sensor, the higher the trust degree of the other data about the two data.

Assume that the value of $\left|x_i - x_j\right|$ stands for the mutual trust degree between Data x_i and Data x_j. Define the trust degree function, b_{ij}, as $b_{ij} = e^{-\left|x_i - x_j\right|}$, whose upper limit is set to be M. When the value of $\left|x_i - x_j\right|$ exceeds the upper limit, M, it suggests Data x_i

$$b_{ij} = \begin{cases} e^{-\left|x_i - x_j\right|} & \left|x_i - x_j\right| \le M \\ 0 & \left|x_i - x_j\right| > M \end{cases}$$

and Data x_j do not trust degree each other, and $b_{ij} = 0$. When the value of $\left|x_i - x_j\right|$ does not exceed the upper limit, M ,

Assume that the system receives parameter data of n sensor (s) in the same environment. The trust degree matrix, B, can be built according to the trust degree function, b_{ij}.

The higher the sum of elements in a row in the credit matrix, B, is, the higher the trust degree the other sensors have for the row of data observed the sensor, and the closer the row of data collected are to the true value.

$$B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix}$$

The data fusion expression based on the trust degree:

$$\bar{x} = \sum_{i=1}^{n} w_i x_i \qquad i = 1,2,\cdots n$$

Where, w_i ---The weight of Data x_i collected and loaded by i sensor during data fusion, $\sum_{i=1}^{n} w_i = 1$.

w_i contains all information reflected by the trust degree matrix, B. A group of nonnegative numbers, $a_1, a_2, \cdots a_n$, are adopted, and ensure that

$w_i = a_1 b_{i1} + a_2 b_{i2} + \cdots a_n b_{in}$ $(i = 1,2,\cdots n)$. According to the trust degree matrix, B, w_i is transformed into the matrix form, $W = BA$, where, $W = [w_1, w_2, \cdots, w_n]^T$, $A = [a_1, a_2, \cdots, a_n]^T$. The matrix is a non-negative matrix. The symmetric matrix has the maximum eigenvalue $\lambda(\lambda > 0)$, and:

$$W = \lambda A$$

The weight of the numerical value measured by various sensors can be obtained

$$\frac{w_i}{w_j} = \frac{a_i}{a_j} \qquad i, j = 1,2,\cdots n$$

through the following equation.

$$\bar{x} = \frac{\sum_{i=1}^{n} a_i x_i}{a_1 + a_2 + \cdots a_n}$$

The fusion results of data obtained by all sensors are:

3.2. Data Node Fusion in the Aggregation Layer based on the Weighted Average Fusion

In the wireless measurement and control system under the greenhouse environment, the data collected by different sensor nodes belong to different types of data. Therefore, during data fusion, it is necessary to think about how to realize the data fusion of the heterogeneous sensor. The weighted average fusion removes the noise data through the Kalman filter, and the weighted average algorithm is used to conduct data fusion. The weighted average algorithm equation is shown below:

$$y = \sum (z_i * w_i) / \sum w_i \qquad (8)$$

Where, z_i ---The data value of the value collected by sensor nodes at different nodes after data treatment and Kalman filtering;

w_i ---The corresponding weight;

y ---The weighted average and the final value of data collected by sensor nodes.

4. Experimental Analysis of Sensor Data Fusion

In the greenhouse environmental wireless network monitoring system, types of data and technical parameters collected by various sensors are shown in Table 1:

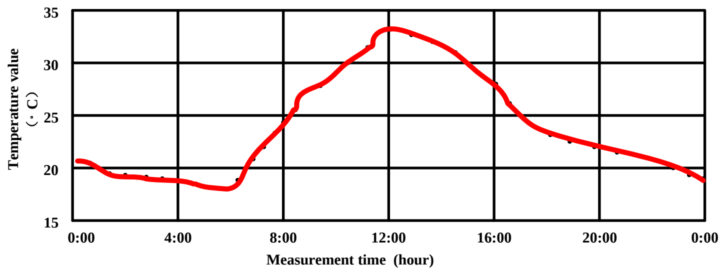
Table 1. Experimental Sensor Parameter Table

Item	Sensor	Type	Signal type
1	Temperature and moisture	AM2301	Numerical
2	Illuminance	JTBQ-6	Simulated
3	CO2 concentration	S-100H	Simulated

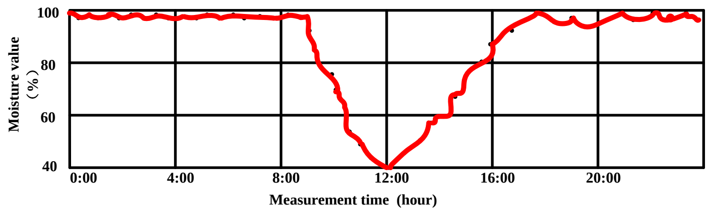
The major control objects of the greenhouse environment are temperature and moisture, while temperature and moisture are different in different areas of the greenhouse. Therefore, two temperature and moisture are set in the inner opposite angle of the greenhouse. Generally speaking, illuminance and CO2 concentration are not directly regulated and controlled, but just act as the basis for the temperature and moisture regulation.

4.1. Data Fusion Results in the Sensor Node Layer

In order to test the fusion results in the sensor node layer, two nodes in Table 1 are employed to collect temperature and moisture, respectively. The collection interval of node data is 10min,and in total 144 data are collected. Figure 4, and Figure 5, are the temperature and moisture filtering results by Node 1 and Node 2. From the filtering results, it can be seen that the measured value of the temperature parameter by two nodes does not fluctuate greatly. The difference between the filtering results and the actual value is not huge. The temperature value of two nodes fluctuates due to the sun radiation at noon. The temperature undergoes smoothing through the filtering. Among the Kalman filtering results of moisture, the greenhouse is at a closed state in the evening. Due to the crop respiration function, the moisture within the greenhouse is close to 100%. However, when the sensor moisture is higher than 98%, data fluctuation will happen. Through Kalman filtering, the data can be smoothed.

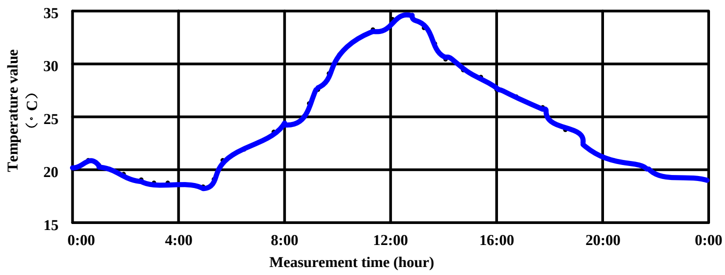


(a) Temperature

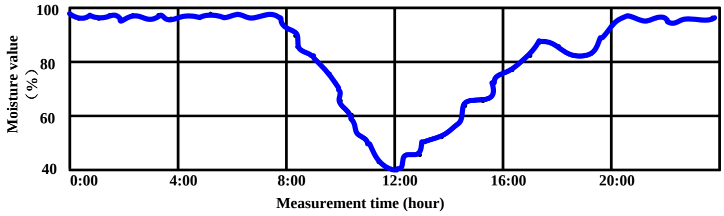


(b) Moisture

Figure 4. Kalman Filtering Results of Node 1



(a) Temperature

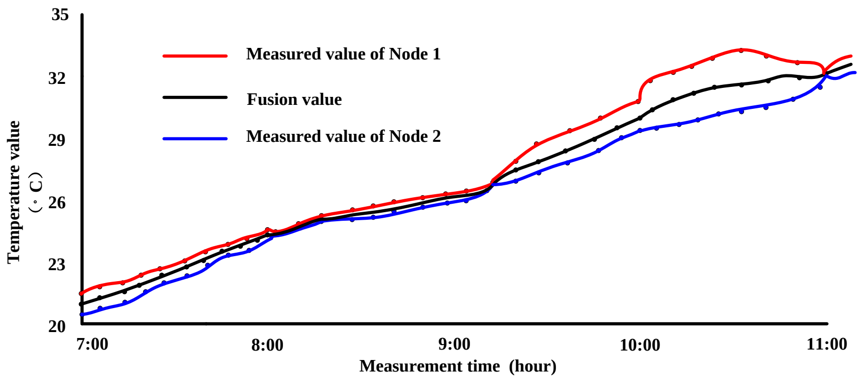


(b) Moisture

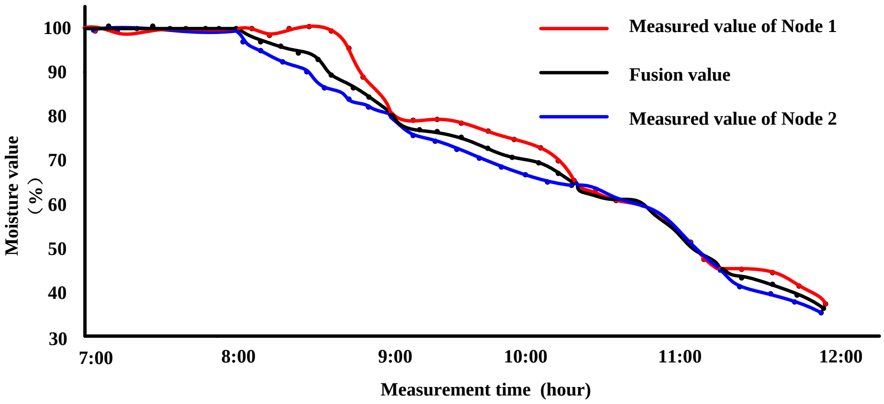
Figure 5. Kalman Filtering Results of Node 2

4.2. Node Fusion Results in the Aggregation Layer

In order to test the aggregation effects, the data with a huge temperature change scope from 7:00 to 12:00 are adopted for the test of fusion effect. Figure 6, is the fusion value of the temperature and the moisture in the greenhouse obtained through the weighted average fusion algorithm. At 8:00 in the morning, the fusion value of temperature and moisture is the average. The side window is opened to ventilate at 8:00 in the morning. Since the east side of the test greenhouse is empty, the west side is another greenhouse. The natural ventilation realizes the temperature and moisture exchange within the greenhouse through the east window. The temperature and moisture of Node 2 at the east side of the greenhouse declines rapidly, and the temperature and moisture at the west side of the greenhouse starts changing one hour later. Through the weighted average fusion, the change of the temperature and moisture fusion value is closer to that of Node 2, which can reflect the moisture and temperature changes within the greenhouse more. After 10:00, the outside and the inside of the greenhouse achieves a dynamic temperature balance, and the temperature and moisture fusion value is the average.



(a) Temperature



(b) Moisture

Figure 6. Sensor Fusion Results

5. Conclusion

Based on the wireless sensor network, this paper builds a multi-sensor fusion greenhouse environmental monitoring wireless network system based on ZigBee. Concerning characteristics of the wireless network, node/aggregation two-layer fusion method is put forward. Kalman filtering is adopted to conduct fusion of the sensor node layer. The weighted average method is employed to achieve node layer fusion. Experimental results suggest that the two-layer fusion can improve the measurement precision and stability of the wireless monitoring network.

Acknowledgements

This work is supported by Chinese Universities Scientific Fund(DC201501059).

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