Internet of Things and Cloud Computing
2021; 9(1): 10-15
http://www.sciencepublishinggroup.com/j/iotcc
doi: 10.11648/j.iotcc.20210901.12
ISSN: 2376-7715 (Print); ISSN: 2376-7731 (Online)

Application of Multi-sensor Data Fusion in Greenhouse

Li Guangzhong

Department of Computer Science and Technology, Shandong Agricultural University, Taian City, China

Email address:
gzhl@sdau.edu.cn

To cite this article:
Li Guangzhong. Application of Multi-sensor Data Fusion in Greenhouse. *Internet of Things and Cloud Computing*. Vol. 9, No. 1, 2021, pp. 10-15. doi: 10.11648/j.iotcc.20210901.12

Received: April 7, 2021; **Accepted**: April 19, 2021; **Published**: April 23, 2021

Abstract: With the development of communication, computer and sensor technology, the application of Internet of things technology to agricultural monitoring is the trend of modern agricultural development. Real time and accurate acquisition of farmland environmental information is the basis of precision operation and intelligent management of agriculture, and it is also an important part of agricultural information construction. A farmland environment information monitoring system based on wireless sensor network is designed, crop growth environment parameters are collected by sensor nodes distributed in the field, using CC2530 to build ZigBee data transmission network, the information transmission between ZigBee network, GPRS network is realized by embedded gateway, and the remote monitoring of farmland environmental information is realized. Before data is transmitted, The negligent errors in the measurement data are excluded by Grubbs' criterion, then the rest of the data are preprocessed based on the arithmetic mean and the batch estimates, lastly the data are fused using adaptive weighted fusion algo-rithm in the condition of minimal mean square error. The results show that the data by hybrid algorithm has perfect accuracy and minimal error. Using this hybrid data processing method, a large number of data can be fused into a data closest to the real situation, and more accurate environmental information can be obtained. The practical results show that, this solution enhances accuracy and reliability of the greenhouse environment detection. This system improves the information level of greenhouse planting, and applys to the management of greenhouse.

Keywords: ZigBee, Grubbs' Criterion, Self-adaptive Weighting Fusion Algorithm, Error

1. Introduction

China's agricultural development mode is gradually changing to the mode of modern agriculture. The main goal of agricultural research is to apply people's science and technology to agriculture and improve agricultural economic benefits. [1] After the third information industry, the Internet of things comes into people's sight, and quickly penetrates into every corner of life. Agricultural Internet of things applys the advantages of Internet of things technology to agriculture, in order to solve the problems encountered in agricultural production, so as to improve the efficiency of agricultural production.

Environmental factors affect the growth of crops in essence, the healthy growth of crops is inseparable from a good growth environment, timely and accurately grasp the environmental factors of crop growth is the guarantee of the healthy growth of crops. In order to realize the information and intelligence of greenhouse, this paper designs a greenhouse monitoring system based on Internet of things technology. It uses sensors to monitor various environmental parameters (such as temperature and humidity, illumination, carbon dioxide concentration and other environmental parameters) of greenhouse in real time. In the process of data transmission, it carries out fusion processing, so as to obtain more accurate environmental information. The ultimate goal is to make the greenhouse crops (greenhouse crops take cucumber as an example) in the best growth environment in the reverse season, which is conducive to the high quality and high yield of the crops in the reverse season.

2. Design Principle and System Structure

The whole information monitoring system is mainly composed of information collection terminal, controller gateway, client and so on. The system design shows in Figure 1. The sensor of information acquisition terminal collects the environmental data of air temperature and humidity, soil temperature and humidity, and light intensity in the greenhouse, and then transmits the collected data to the ZigBee coordinator through ZigBee wireless network; ZigBee coordinator contains D/A conversion module and other electronic components, and the coordinator transmits the data to the controller gateway; The controller gateway transfers the data from ZigBee coordinator and GPRS data to each other for two-way data transmission and protocol conversion. The client stores the collected data locally in time, which can be used by the administrator to view the current situation and historical records at any time, and generate the corresponding line chart, which is convenient for the comparison and analysis of data.

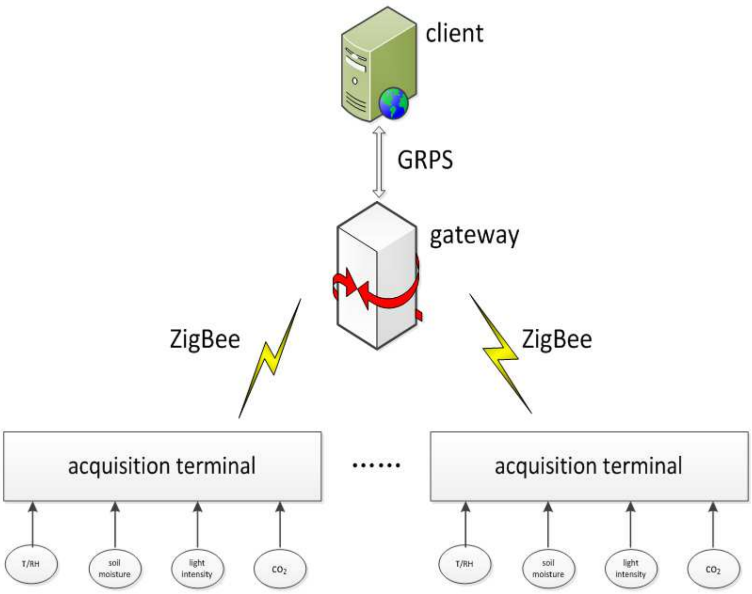

Figure 1. *Structure of monitoring system.*

3. Hardware Design of Monitoring System

3.1. Hardware Design of Data Acquisition Terminal

3.1.1. Soil Moisture Sensor

Fds-100 soil moisture sensor [2] uses the principle of electromagnetic pulse to measure the soil dielectric constant according to the propagation frequency of electromagnetic wave in the medium, so as to obtain the soil volumetric water content. It is composed of power supply module, transmission module, drift and temperature compensation module, data processing module, etc. It uses FDR frequency domain method to accurately measure the moisture content of different soil profiles in real time. Measuring range: 0~100%, measuring accuracy: ±3%, measuring frequency: 100MHz, working voltage: 5~12V, working current: 21~26ma, output signal: 0~2vdc. The sensor shows in Figure 2.

Figure 2. *Soil moisture sensor.*

3.1.2. Temperature and Humidity Sensor

Am2302 digital temperature and humidity sensor [3] is a temperature and humidity composite sensor with calibrated digital signal output. It uses special digital module acquisition technology and temperature and humidity sensing technology to ensure that the product has high reliability and excellent long-term stability. The sensor consists of a resistive humidity sensor and a NTC temperature sensor, and connectes with a high-performance 8-bit MCU. Power supply: 3.3-6v DC, humidity accuracy:±2% RH, humidity range: 0-100% RH, temperature accuracy:±0.5°C, temperature range: - 40-80°C. The sensor shows in Figure 3.

Figure 3. *Temperature and humidity sensor.*

3.1.3. Carbon Dioxide Sensor

The carbon dioxide sensor tgs4161 [4] is a new miniaturized, low-energy solid-state electrolyte carbon dioxide sensor with a detection range of 350-10000 ppm. The CO_2 sensing part consists of two electrodes formed by solid electrolyte. It also has a printed heating base. It measures the content of CO_2 by monitoring the electromotive force generated between two electrodes. At the top of the sensor, there is an adsorption device to prevent the interference of other gases. The output EMF of tgs4161 is linear with the logarithm ratio of CO_2 content. The sensor has long-term stability and excellent moisture resistance. The sensor shows in Figure 4.

Figure 4. *Carbon dioxide sensor.*

Figure 5. *Optical sensor.*

3.1.4. Optical Sensor

Bh1750 optical sensor [5] has built-in 16 bit analog-to-digital converter, which can directly output a digital signal without complicated calculation. This light sensor calculates the voltage to obtain effective data. It measures data directly through a photometer. Power supply voltage: 3-5v, interface: I^2C, range and precision: 1~65535lx. The sensor shows in Figure 5.

3.1.5. MCU

MSP430F5438 [6] of TI company is selected as the processor chip of controller gateway and data acquisition terminal. The chip is famous for its low power consumption. The working voltage of MSP430F5438 is 1.8~3.6 V, and it can run the device with the peak value of 25 Hz with the lowest power consumption. It is very suitable for the occasions requiring long-time power supply.

3.1.6. ZigBee

ZigBee network works [7] in the free 2.4GHz ISM band, the theoretical data transmission rate is 20~ 250kbgs, and the data is transmitted between nodes through radio waves, which has high communication efficiency and low energy consumption. Each greenhouse has seven sensor nodes, one of which is selected to connect with ZigBee coordinator, and the remaining six nodes are connected with different types of sensors respectively. The connection structure adopts star network topology. When the distance between the sensor node and the ZigBee coordinator node is more than 100m, the data packet will be lost. Therefore, when deploying nodes, the distance between each sensor node and ZigBee coordinator node is maintained at about 70m. [8]

ZigBee coordinator adopts CC2530 processor of TI company. [9] The chip integrates high-performance RF transceiver core, enhanced 8051 core, built-in 8-channel 12 bit DAC, 2 UART interfaces and 21 information acquisition programmable I/O interfaces, providing 101dB link quality, good receiving sensitivity and strong anti-interference ability. CC2530 application circuit structure is very simple, only a small number of external components can achieve the wireless transceiver function of the node. The Hardware structure of data acquisition terminal shows in Figure 6.

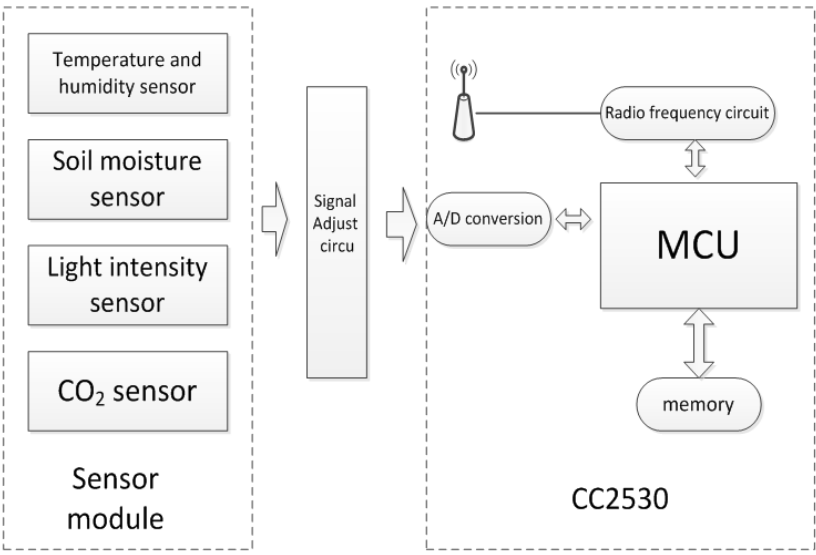

Figure 6. *Hardware structure of data acquisition terminal.*

3.2. Design of Controller Gateway

The controller gateway controls the data acquisition and transmission of sensors, and also controls the data exchange between sensor nodes [10]. ZigBee coordinator is connected with the controller gateway through UART0, and GPRS communication module is connected with the controller gateway through uart1. Both UART0 and UART1 interfaces can provide up to 230.4kb/s data transmission rate. The GPRS communication module is ME3000 embedded with TCP / IP protocol_ V2, the communication module can use the built-in protocol to communicate with the cloud server, and the controller can send AT instructions to connect with the GPRS module and transmit data.

4. Data Preprocessing

The estimation algorithm is based on the reliable initial measurement value. In multiple measurements of a single node, it can not guarantee that each measurement value is correct, so we need to remove the abnormal data first.

Abnormal data [11] refers to the small probability error that the measurement value exceeds the normal measurement error range caused by some unexpected abnormal factors in the measurement process. When wireless sensor networks collect data, abnormal data will inevitably appear due to external interference. Data with large errors will interfere with the test results, and even distort the test conclusions. Eliminating the large errors in the measurement data can improve the adaptive speed and accuracy of data fusion.

Practice has proved that the accuracy of Grubbs' criterion [12] is higher when testing a small number of data. In order to ensure real-time performance, the number of data collected per unit time should not be too much, so this study selects Grubbs' criterion to eliminate large errors.

Grubbs' criterion uses to test the consistency of a group of measurements and eliminates outliers in a group of measurements, and it also uses to test the consistency of the mean values of multiple groups of measurements and eliminates outliers in multiple groups of measurements.

Let the measurement data of a node in unit time be x_1, x_2, x_3,…, x_i,…, x_K, then the arithmetic mean value of the measured data of this node:

$$\overline{x}=\frac{1}{k}\sum_{i=1}^{k}x_i$$

The residual error of the ith measurement is: $V_i = x_i - \bar{x}$

The corresponding standard deviation of this group of data is: $\sigma = \sqrt{\frac{1}{k-1}\sum_{i=1}^{k}V_i^2}$

According to the commonly used Grubbs' criterion critical value table, find out the critical value G0 (n,α), that is p[g≥G0 (n,α)] =α (significance level α is generally 0.05 or 0.01, that is, the confidence is 95% or 99%), in order to improve the measurement accuracy, the confidence is 95%.

If the ith measurement data Xi satisfies the following conditions:

$$|V_i| \geq g0(n, \alpha)\sigma,$$

Xi is removed.

Repeat the above process for the remaining data until all data meet the requirements.

5. Data Fusion Algorithm Based on Adaptive Weighting

In order to verify the system, the dominant environmental factors of early spring cucumber in greenhouse during the fruiting period in March selecte as the experimental objects, At this time, the growth of the plant is large and the yield of melon is high. The suitable temperature in the daytime is 25-32°C. It is necessary to create longer illumination time in the daytime; The humidity requirements of cucumber are different in different growth stages, and the relative humidity required in fruiting stage is 70% - 80%.

The data in the table 1 are 24 humidity data collected by sensors of 8 data collection points in the greenhouse for three times. After using Grubbs' Criterion to eliminate the abnormal data in the previous chapter, the 21 measurement data divide into 3 groups.

Table 1. *Measurement data after eliminating abnormal data.*

	1	2	3	4	5	6	7
first group	73.4	74.4	75.8	74.2	76.8	74.3	73.6
second group	73.9	75.6	75.3	74.7	76.7	75.0	74.9
third group	76.7	75.2	76.0	73.9	74.9	73.5	74.2

The data processed by arithmetic mean and batch estimation [13] shows in Table 2.

Table 2. *Processed data.*

	1	2	3
value	74.91	75.07	74.52
σ	0.737	0.299	0.366

The local data obtained after abnormal data processing adopts adaptive weighted fusion algorithm [13-17], it obtains more effective fusion effect than average estimation.

There are n sensors in simultaneous interpreting of the same area, and the reliability and accuracy of each sensor are different. Then, we use the adaptive weighted fusion algorithm to calculate the optimal weighting operators corresponding to the optimal sensor under the optimal mean of the minimum mean square error of all sensors, so that achieve the optimal values of the fused values.

Suppose there are n sensors whose variances are σ_1, σ_2,…, σ_n; The true value to be estimated is X, and the measured values of each sensor are X_1, X_2,…, Xn, where X_1, X_2,…, Xn is independent of each other and is the unbiased estimation of X. the weighting factors of each sensor are W_1, W_2,…, Wn, The fusion of W_1, W_2,…, Wn value and weighting factor satisfy

$$\bar{X} = \sum_{p=1}^{n} W_p X_p$$

In the formula, W_P is the weighting factor of the p-th sensor, and there is

$$\sum_{p=1}^{n} W_p = 1, 0 \leq W_p \leq 1$$

Because $X_1, X_2, \ldots, X_n$ is independent of each other and is an unbiased estimate of X, then the total mean square error writes as

$$\sigma^2 = E[(X - \bar{X})^2] = E[\sum_{p=1}^{n} W_p^2 (X - X_p)^2] = \sum_{p=1}^{n} W_p^2 X_p^2$$

According to the method of calculating the extremum of multivariate function, the weighted factors corresponding to the minimum total mean square deviation calculates as follows

$$W_p^* = \frac{1}{\sigma_p^2 \sum_{p=1}^{n} \frac{1}{\sigma_p^2}}$$

Corresponding minimum mean square error is

$$\sigma_{min}^2 = \frac{1}{\sum_{p=1}^{n} \frac{1}{\sigma_p^2}}$$

Through the above formula, the optimal weighting factor calculates, and the optimal value after fusion calculates according to the actual measurement value, that is

$$\bar{X} = \frac{\sum_{i=1}^{n} \frac{X_i}{\sigma_i^2}}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}$$

The data in Table 2 bring into Wi, and three groups of weights obtain after calculation: $W_1 = 0.09$, $W_2 = 0.55$, $W_3 = 0.36$. After introducing the weighting factor according to the adaptive weighting model, the system data fusion value is:

$$\bar{X} = \sum_{p=1}^{3} W_p X_p = 74.86$$

Data processing with adaptive weighted data fusion method, although the process is complex, the error of the processing result is the smallest, and the data closest to the real value can be obtained.

6. Conclusion

This paper designs a greenhouse monitoring system based on Internet of things technology, and gives the framework structure of hardware system. Firstly, the data collection module adopts the Grubbs' criterion to preprocess the data, then processes the data based on adaptive weighted fusion algorithm. We carry out data fusion experiments on the main environmental parameters of Spring Cucumber in greenhouse, such as temperature, humidity, carbon dioxide concentration, illumination and so on. The fusion results are close to the real values, which accurately reflect the actual state of the greenhouse and improve the accuracy of data collection. Our work is ultimately of great value for saving energy and improving the accuracy of greenhouse control.

Using data fusion technology in greenhouse intelligent monitoring system will bring many advantages and benefits to the system. It can enhance the robustness and reliability of the system; it can improve the credibility, detection performance and data accuracy of the system, and make the system have better situation awareness and decision-making ability.

References

[1] ZHAO Hong Cai, et al. Research on wireless intelligent monitoring system of cucumber garden based on expert system [J]. Jiangsu Agricultural Sciences, 2017, 45 (17): 215-218.

[2] LI K, et al. Study on rational setting position of soil moisture sensor for greenhouse cucumber based on real-time control irrigation system [J]. Journal of Irri-gation and Drainage, 2015, 34 (7): 18-23.

[3] Kong Guoli et al. Automatic Intelligent Management System of the Temperature and Humidity and Soil Moisture for the Vegetable Greenhouse [J]. Journal of Agricultural Mechanization Research, 2015, 37 (08): 184-188.

[4] Mao Min, Study on Greenhouse Monitoring Systems Based on Internet of Things Technology [J]. Electrical Automation, 2021, 43 (01): 34-36.

[5] Yang Jingwei et al. A Design of Dedicated Carbon Dioxide Monitor System in Facility Agriculture [J]. Journal of Agricultural Mechanization Research, 2014, 36 (06): 127-130+137.

[6] Wang maoli, et al. Research on digital farmland information monitoring system based on Internet of Things technology [J]. Journal of Chinese Agricultural Mechanization, 2019, 40 (9): 158~163, 180.

[7] ZHANG Wei-Cong, et al. Wireless Network Sensor Node Design Based on CC2530 and ZigBee Protocol Stack [J]. Computer Systems & Applications, 2011, 20 (07): 184-187+120.

[8] Liu Yuanyuan, et al. The System Design of Farmland Environmental Monitoring Based on GPRS and Wireless Sensor Network [J]. Journal of Agricultural Mechanization Research, 2013, 35 (7): 229-232.

[9] DUAN Jie, et al. Analysis of strawberry greenhouse information monitoring system based onagricultural internet of things [J]. Modern agricultural science and technology, 2018, 17 (18): 1288-1291.

[10] XIAO Linglu, et al. Design of Farmland Environment Monitoring System Based on Wireless Sensor Network [J]. Henan Science, 2017, 35 (10): 1574-1581.

[11] HUANG Haisong, et al. Study on datafusion of crop growth monitoring based on agricultural internet of things [J]. Jiangsu agricultural science, 2017, 20 (21): 1241-1243.

[12] FAN LeiSong, et al, Data fusion method based on BP neural network in wireless sensor networks [J]. Computer Engineering And Design, 2014, 35 (1): 62-66.

[13] TANG Ya-peng. Data Processing Based on Adaptive Weighted Data Fusion Algorithm [J]. Computer Technology And Development, 2015, 25 (04): 53-56.

[14] HUANG Jian, et al. Application of Multi-sensor Data Fusion in Underground Mines [J]. Coal Mine Machinery, 2015, 36 (7): 242~244.

[15] Chhabra S, Singh D. Data fusion and data aggregation/summarization techniques in WSNs: a review [J]. International Journal of Computer Applications, 2015, 121 (19): 21-30.

[16] Awang A, Agarwal S. Data aggregation using dynamic selection of aggregation points based on RSSI for wireless sensor networks [J]. Wireless Personal Communications, 2015, 80 (2): 611-633.

[17] Rout R R, Ghosh S K. Adaptive data aggregation and energy efficiency using network coding in a clustered wireless sensor network: an analytical approach [J]. Computer Communications, 2014, 40 (3): 65-75.