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# Monitoring Methods and its Application of Carbon Sinks Based on GPRS

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**Abstract:** Scientific and effective monitoring of forest carbon emissions and carbon sinks can provide a scientific basis for national development of low-carbon economy. Due to the limitations of technical conditions and cost, it is very difficult to obtain accurate data of the regional carbon sink by using the existing common means. First, this paper discusses the benefit and weakness of kinds of monitoring methods of forest carbon emissions and carbon sinks. Then, it mainly proposes the way based on carbon flux measurement model, which is based on wireless network technology, combined with the continuing dynamic perceived information needs of carbon flux tower. In addition, the article develops the smart sensor nodes to meet the multi-scale, multi-objective time and space requirements. The node and the system had successfully accomplished the online auto-monitoring of the CO2 concentration, temperature and humid value of the monitoring area of Taihu town in Linan, Zhejiang Provice of China, which lays the foundation for building carbon emissions, carbon quantitative monitoring comprehensive platform, real-time release carbon balance regional information. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** Carbon sink, $CO_2$ concentration, Assessment method, Carbon exchange.

## 1. Introduction

Extreme weather in recent decades has brought a tremendous negative impact on human life and property safety, food security, and it has drawn the attention of the world [1-4]. According to statistical data and the related research, dominated by $CO_2$, a significant increase in greenhouse gases cause global warming (Fig. 1), which is the main reason for the extreme weather. Facing a severe global climate change, from the Kyoto Protocol to the Copenhagen conference, governments around the world are actively involved in international cooperation to address climate change, attempt to agree on the reduction emission of greenhouse gas, and lay out a national target of carbon reduction, according to "the global temperature can not exceed 2°C". To incentive countries to carry out a variety of actions to mitigate climate change, the Kyoto Protocol establish a more flexible cooperation mechanisms to fulfill the emission reduction tasks between different countries by means of carbon trading market.

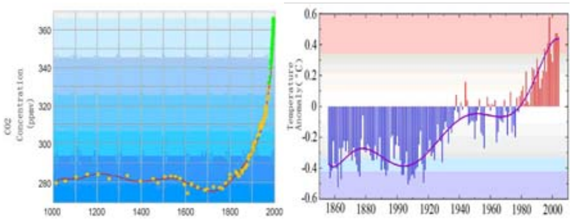

**Fig. 1.** 1000 global $CO_2$ changes in 1000 years (left) and 1860' Global average temperature change (right).

EU countries, such as Germany, Belgium, the Netherlands, took the lead through carbon emissions trading system, and established an international carbon exchanges-European Climate Exchange. Till November of 2009, the trading volume of emission rights has reached more than 20 million tons of carbon. In 2010, Beijing carbon Exchange issued Chinese carbon trading standards – "Panda standards". Carbon reduction targets and carbon trading market not only reinforce the importance of reduction and increase sinks, but also highlight the urgency and necessity of the quantitative monitoring of carbon emissions and carbon sinks.

As a huge "carbon sinks", forest ecosystems is an excellent representation in the research on carbon sink monitoring technology, which is of great significance to measure the effect of forest in the carbon cycle accurately and evaluate the impact of CO2 on climate change scientifically. Due to the limitations of technical conditions and cost, it is very difficult to get accurate data of the regional carbon sink by existing common means. The method of Sampling plot biomass and the method of Carbon flux observation can only monitor a small amount of fixed locations precisely. We can adopt the Land process model and the Atmospheric retrieval model to estimate carbon sinks in a large-scale.

But the data obtained are not accurate and stable because of the restriction of the input parameters and assumption terms. Recent researches of Chinese carbon budget estimation, which are reported on prestigious journals such as "Nature", are shown in Table 1.

**Table 1.** Chinese terrestrial ecosystem carbon sequestration statistics.

| Method | Carbon sink (Tg) | Category |
|---|---|---|
| Survey data of forest resources and satellite retrieval estimates [4] | 75.6±48.1 | China Forestry |
| Atmospheric inversion model [5] | 350±330 | Chinese terrestrial ecosystem |
| Land surface process model In TEC [6] | 189±23.5 | Chinese terrestrial ecosystem |

It shows that the results obtained by different carbon budget estimation methods have great differences: the estimated results which obtained by using biomass, soil carbon survey data and satellite remote sensing resources inventory data shows that the average annual amount of fixed carbon of the terrestrial ecosystem in China is 0.177 ± 0.073 Gt; the estimated results which is obtained by Land surface process model shows that the average annual amount of fixed carbon of the terrestrial ecosystem in China is 0.173±0.039 Gt; however, the data obtained by Atmospheric inversion is 0.35±0.33 Gt. There is a vast gap between the first two results and the last one.

American atmospheric scientists [7], adopt an inversion method to obtain results by using the atmosphere and ocean models, and get the value of the atmospheric $CO_2$ concentration. The results show that the total amount of carbon sink in the Northern hemisphere terrestrial can reach 2 to 3 Gt [8]. Beer adopts an eddy covariance method for the determination of vegetation carbon flux [9]. The results show that carbon sinks reach up to 2 Gt per year in Northern hemisphere temperate forest. There is such a large difference between the results obtained by different researchers with different models and methods, which shows that the current estimation techniques of carbon sinks have considerable uncertainty. Therefore, the new methods to obtain the carbon sink data more accurately are urgently needed.

The main reason for the deviation of the above data is that those models are limited by using the sparse observational network nodes. Consequently, the insufficient coverage of the study area can not reflect the real situation of the atmospheric changes in the region. The use of wireless sensor network observing techniques can overcome the shortcomings of limited observation node and data representativeness. Because, the features of wireless network technology, such as wide range of monitoring, long duration, perceived ability and timely transmission of information, made it very superior for the monitoring of carbon emissions and carbon sinks. In additional, the large-scale and global carbon budget monitoring can provide a scientific basis for the assessment of carbon trading by using wireless network node. Since the 1980s, the State Forestry Administration established a number of forest eco-system research station and investigated the amount of $CO_2$ that the forest absorbed and fixed. They made some progress and breakthroughs in the monitoring of forest ecosystems and carbon sinks. But in the forest ecosystem, the species, structure and environment are abundant, diverse and complex, respectively. These characteristics cause that the current research stations can not meet perfectly the national demand, i.e. the quantitative monitoring of carbon emissions and carbon sinks, neither in the scope of monitoring nor in monitoring capabilities.

Forest ecosystems have two main characteristics: a wide range of spatiotemporal heterogeneity and scale complexity. The construction of large-scale carbon emissions and carbon sequestration monitoring system should base on these two characteristics. The system can continuously monitor some main parameters and key indicators of the urban and forest ecosystems in a wide range of region, and has long-term stability. It can not only helps us assess status quo of carbon budget quantificationally and objectively, but also provide a strong scientific and technological support for coping with climate change and enhancing the capacity for sustainable development.

As shown in Fig. 2, the carbon cycle of forest system is composed of two parts: above and below ground. The part above the ground can absorb $CO_2$ by vegetation photosynthesis, and the part underground can absorb and emit $CO_2$ through root respiration, soil microbial respiration and soil animals' heterotrophic respiration. The ratio of absorption and emission is influenced by many factors, such as size and type of soil porosity, soil temperature and moisture, wind velocity and $CO_2$ concentration gradient in the atmosphere. These factors are great challenges to the monitoring of forest carbon sinks. Traditional monitoring methods for forest carbon sinks are mainly concentrated in the monitoring of the aerial parts. It inverts changes of carbon by estimating the amount of biomass in the fixed sample and by the real-time monitoring of carbon flux.

But the uncertainty of this method is obvious because there are few observation points and it is difficult to achieve the common international carbon trading premise requirements of "Measurable", "reportable", "verifiable". Owing to lack of uniform standards, the results obtained by different monitoring methods vary so greatly.

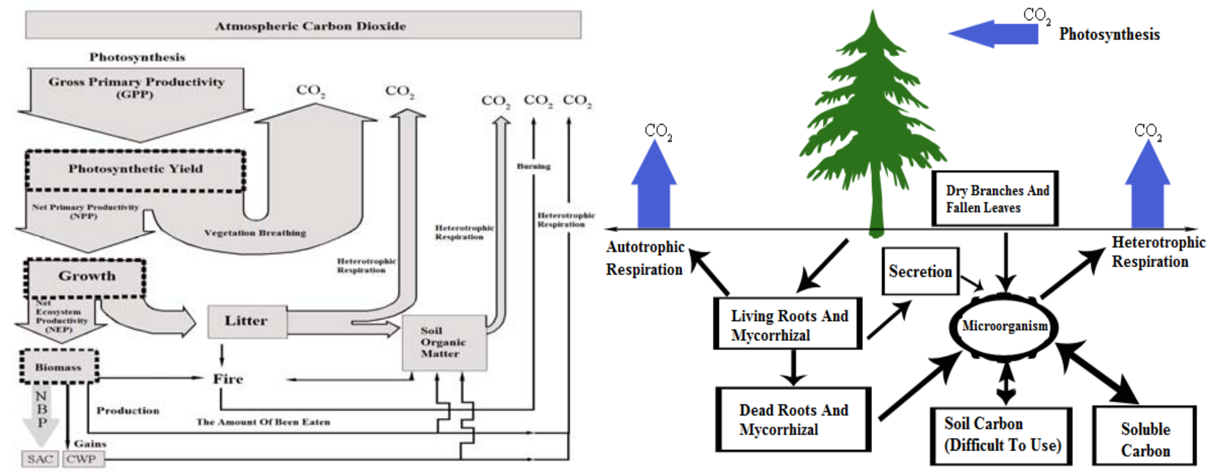


**Fig. 2.** Forest carbon cycle system (left) and soil respiration (right).

The monitoring system for carbon emissions and carbon sinks, which is based on large-scale sensor network and integrate the carbon flux tower, remote sensing, ground plots and other technologies, can help to evaluate the role of forests in global carbon cycle quantificationally and provide more accurate and credible basis for carbon trading.

This system can acquire data synchronously in real-time and on a large scale. It helps to carry out in-depth study of key biological process, physical and chemical processes in forest system.

In this paper, the smart sensor nodes are used to monitor carbon emissions and carbon sinks. We construct a systematic estimation models for forest carbon budget and realize the process simulation of forest ecological environment. And the scientific monitoring method of forest carbon sinks is investigated to achieve the purposes of quantitative, large-scale, comprehensive, long-term, continuous, real-time, remote and automatic way to obtain the relevant data.

The remainder of this paper is organized as follows. Section 2 introduces the current development situation, and discusses the insufficiency of carbon emissions and carbon sinks. Section 3 proposes a monitoring system. Section 4 results. Followed by the conclusion of results in Section 5.

## 2. The Current Research Situation of Monitoring Carbon Emissions and Carbon Sinks of Forest

As the main body of the terrestrial ecosystem, forest ecosystems , in total, account for about 77 % of the total reserves of the global terrestrial carbon pool, and take a very important role in the absorption of greenhouse gases, climate change mitigation, maintenance of ecological balance.

In the 20 years between 1981 and 2000, the total carbon sequestration of forest ecosystems in China was about 2.99 billion tons, the forest vegetation biomass carbon sequestration and forest soil carbon sinks were 15.8 million tons and 1.41 billion tons, which can offset the 22.6 % of total industrial emissions during the same period [5]. As a huge "carbon sinks", forest ecosystems is an excellent representation in the research on carbon sink monitoring technology which is of great significance to measure the effect of forest in the carbon cycle accurately and evaluate the impact of $CO_2$ on climate change scientifically.

Since the late 1980s, Chinese researchers carried out extensive research for different regions, various types of ecosystem carbon budget, and made some progress in some of major areas [10, 11]. The researchers try to determine the capacity of the regional ecosystem carbon budget by measuring the indicators of the terrestrial carbon sink and by building the model of the terrestrial carbon sink.

The assessment of carbon budget for regional-scale terrestrial ecosystem is the comprehensive assessment, which refers to carbon budget of all types of ecosystems (forests, grasslands, wetlands, farmland, etc.) for specific regional scale (watershed, ecological zone, national, continental or global).

At present, technologies are applied widely including inventories survey of plant biomass and soil carbon storage, flux observations, satellite remote sensing, inversion of atmospheric $CO_2$ concentration and ecosystem model simulation etc. [12].

# 3. Design of Smart Sensor Node

## 3.1. Design Requirements and System Scheme

The sensor node need to gather the parameters of carbon sinks, carbon flux, carbon emissions monitoring is based on a variety of different sensing device for accessing environmental information and carbon flux of fixed observation tower, and the communication between the sensor node and the center uses the way of wireless networks. The basic principle of carbon budget monitoring is calculated by using the model, which integrates gradient changes of regional concentration of $CO_2$. The sensor node needs to access the data of concentration of $CO_2$ and other environmental parameters. System design scheme is shown in Fig. 3. The monitoring system based on a Wireless Network can be divided into three parts: intellectual data monitoring nodes, wireless communication network and remote monitoring center for the Carbon Sinks [13, 14]. A lot of intellectual data monitoring nodes, which are distributed in monitoring area, can dynamically constitute a monitoring network, in which each intellectual node can collect parameters such as concentration of $CO_2$, wind speed, latitude and longitude, windward, height, humidity and temperature.

Then the data from the intellectual nodes is transferred to a remote monitoring center by the base station using a GPRS network, and the monitoring center can analyze and process the data. According to analysis models, the system can calculate the carbon emissions and realize the remote monitoring of on-site parameters and state information. And it can realize the visualization of carbon emissions of monitoring areas and statistic analysis by using its background database, and provides support for decision-making in carrying out the policy for conserving energy and reducing emissions. Finally, it can provide a scientific basis for the assessment of carbon trading.

The whole monitoring system has some useful characteristics such as large network capacity, flexible disposition, low cost, and minor influence on the natural environment.

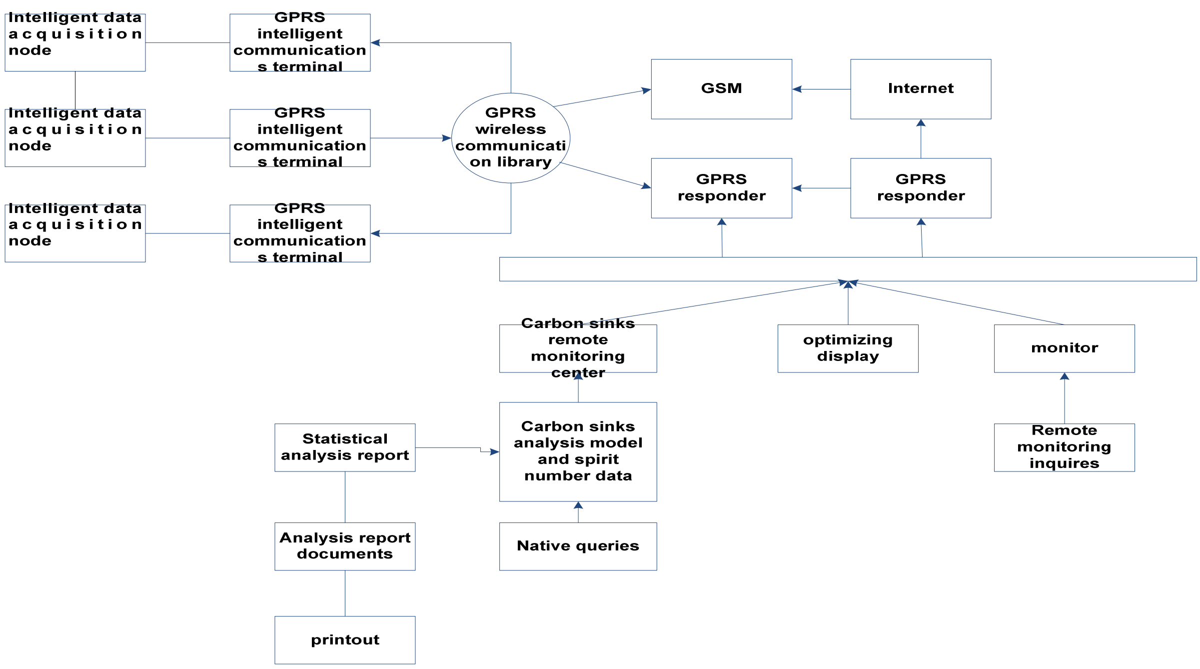


**Fig. 3.** Scheme of the system.

### 3.2. Design of the Intellectual Monitoring Node

Monitoring nodes, as the basic unit of the monitoring area of the carbon emissions, are the basic units to realize the monitoring function. At present, the major functions of the monitoring nodes are listed as follows [15, 16]:

1) Collecting the data of concentration of $CO_2$, wind speed, latitude and longitude, windward, height, humidity and temperature of the monitoring area. The sensors installed on the monitoring nodes can meet the above needs.

2) Realization of the communication between the nodes and remote monitoring center.

Fig. 4 shows the systematic structure of the monitoring nodes, which can be divided into five modules: MCU module, wireless communication transmitter, kinds of sensing module, power module, display module, control module, real-time-clock module and data store module. The aforementioned modules are unexceptionally placed in the different height of the forest according to flux tower theory. All modules have gone through a waterproofing process. The power module provides electricity for the other modules. MCU module is key module, which can process all kinds of sensor signals, and collect and memorizes the related information, and controls the motor, and realizes the communication between the nodes and remote monitoring center. Kinds of sensing module collects the parameters of $CO_2$, wind speed, latitude and longitude, windward, height, humidity and temperature, in the destination layer. Display-module displays all the parameters of kinds of sensors, information of real-time-clock and state information of the system. Control module control the motor which collects the atmosphere of $CO_2$ of the target layer in the forest, work status of display module and wireless communication module in order to lowing down power consumption and prolong the life of the node. Data store module can store the data of all parameters, and send the data to the center at intervals. Real-time clock module provides the reference information of real time to analysis-model when we calculate the data of the carbon sinks.

### 3.3. Design of Hardware for the Intellectual Monitoring Node

#### 3.3.1. Design of the Power Module

The input power of the Intellectual Monitoring Node is a voltage of 12 V. A nickel-hydrogen batteries or a storage battery (12 V) can be used as power supply. Besides, the sensor of $CO_2$ and atmosphere can share the same batteries.

The input voltage can be adjusted to a digital power output of +5 V through the LM2576 chip, then supply power for the pump of $CO_2$, GPRS module, display module, real-time clock module and temperature-humidity sensor. The input voltage can be adjusted to a digital power output of +3.3 V through the TP4054 chip, and provide power for MCU module, real-time clock module and sensor module. The power module is illustrated in Fig. 5.

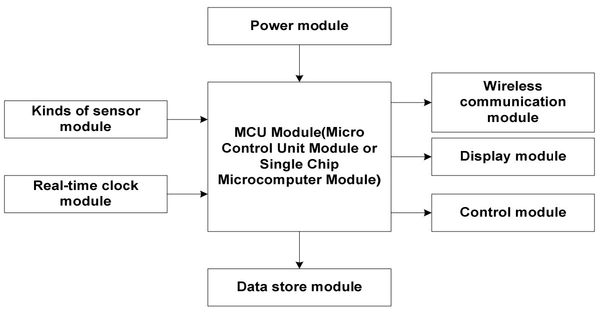


**Fig. 4.** Systematic structure of the monitoring nodes.

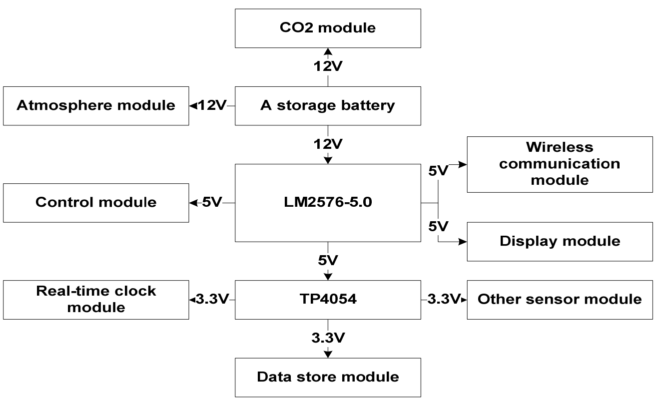


**Fig. 5.** Power module.

### 3.3.2. Design of Central Control Module

The MCU for the central control module is the MSP430F149, manufactured by Texas instruments. The MSP430F149 is also a kind of MCU with low power consumption, which makes it ideally suitable for the design requirement of lower power consumption. Fig. 6 also shows the central control module, which includes the MCU module, data store module, real-time clock module, 232-UART module, and LCD display module. All the parameters are input into MCU through kinds of digital sensor. Then, MCU will store the all parameters – $CO_2$, wind speed, latitude and longitude, windward, height, humidity and temperature, according to the time sequence when they were collected. Finally, the MCU will be communicating via the GPRS module. In the meantime, the MCU microprocessor is connected respectively with the JTAG module which is used as program, a real-time clock module, 232 UART module which is the interface of some digital sensors or communication interface, data store module, and LCD display module to realized functions such as real time reading and writing, communication based on RS-232,485 protocol, data storage and historic data storing.

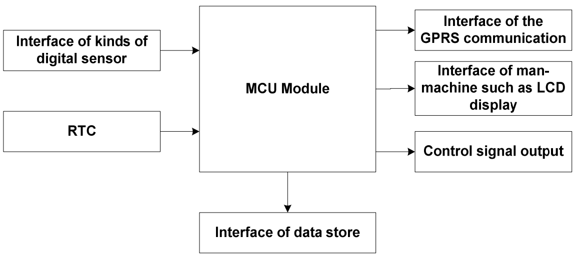


**Fig. 6.** Central control module of the intellectual monitoring node.

### 3.3.3. Design of the Interface Circuit for the Peripheral Components

1) Interface Circuit of the LCD Display Component.

LCD display component displays on-site information of environment. The module includes 8192 Chinese fonts which are consisted of dot matrix of 16*16, its display resolution is 128(w)*64(h), display mode is FSTN, positive (or Black-Negative), driving method is1/64 Duty, etc. Fig. 7 shows its interface circuit.

2) Interface Circuit of the RTC Component.

A real-time clock module provides the real-time information for the intellectual monitoring node and for the analysis model of carbon sinks. Fig. 8 shows its interface circuit. The two ports of 1302_x1 and 1302_x2 connect 32768 HZ of the quartz crystal oscillator in the Fig. 8.

3) Interface Circuit of Wireless Communication Module (GPRS Module).

The on-site information, which is collected by each sensor, can be sent to the monitoring center or stored the memory chip on the intellectual monitoring node. Communication between the node and the monitoring center is done by the GPRS module which is a plug and play GSM modem with a simple to interface serial interface. We can use it to send SMS, make and receive calls, and do other GSM operations by controlling it through simple AT commands from micro controllers and computers. The wireless communication module uses the highly popular SIM300 module for all its operations. It comes with a standard RS232 interface which can be used to easily interface the modem to micro controllers and computers. Fig. 9 shows the interface circuit of GPRS module and MCU.

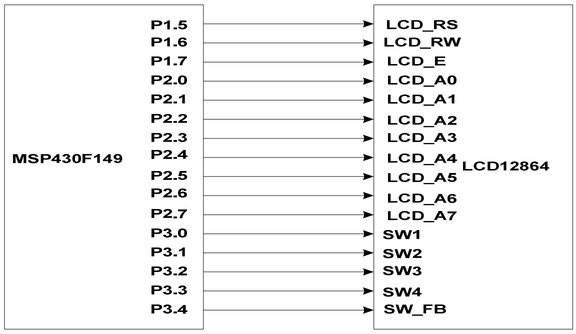


**Fig. 7.** Interface circuit of the LCD display component.

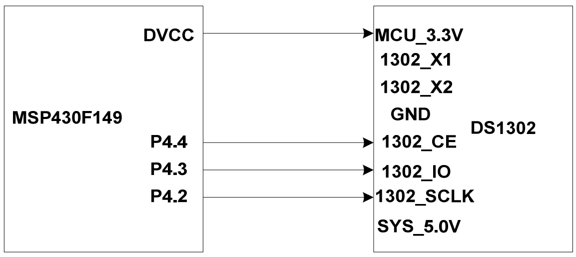


**Fig. 8.** Interface circuit of the RTC component.

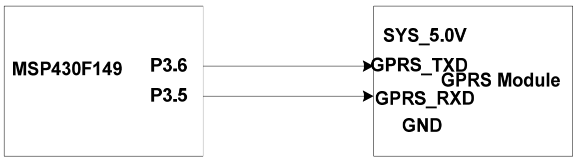


**Fig. 9.** Interface circuit of GPRS module.

4) Interface Circuit of the other Component.

Fig. 10 shows the interface circuit of the JTAG debug port, which downloads the program to the MCU.

B-530 module (sensor of $CO_2$) is designed to measure $CO_2$ level in the air. The product is maintenance free, low cost and integrated into other equipments especially. It simultaneously transmits a calibrated digital and output signal, so it has two available outputs: UART and AVO. Fig. 11 shows the interface circuit of B-530 module and interface circuit of DTH sensor.

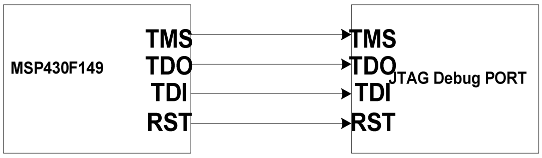


**Fig. 10.** Interface circuit of JTAG debug port.

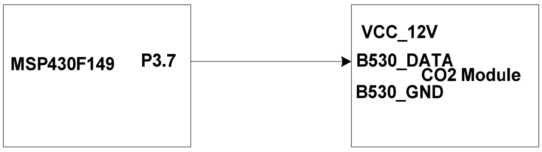


**Fig. 11.** Interface circuit of $CO_2$ sensor.

The DHT11 is a relative cheap sensor for measuring temperature and humidity. This sensor includes a resistive-type humidity measurement component and a NTC temperature measurement component, and connects to a high-performance 8-bit microcontroller, offering excellent quality, fast response, anti-interference ability and cost-effectiveness. The sensor has three lines, GND, +5 V and a single data line. By means of a handshake the values are clocked out over the single digital line. A 5 K pull-up resistor is recommended in the digital signal output port, the interface circuit of DHT11 sensor is showed in Fig. 12.


**Fig. 12.** Interface circuit of the DHT11 sensor.

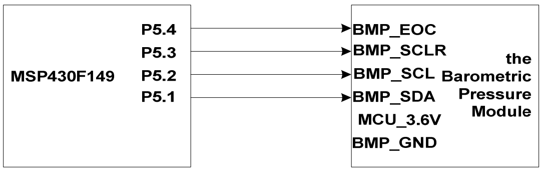


**Fig. 13.** Interface circuit of the barometric pressure module.

We set that the system samples two minutes per an hour, there are 4 samples in two minutes, each sample includes parameter data of 32 bytes. So, there are data of 128 bytes, there are more 270 K data in three month that is lifetime of the battery of the system. According to the above, we select the chip of AT24C512. The AT24C512 provides 524,288 bits of serial electrically erasable and programmable read only memory ($E^2$PROM) organized as 65,536 words of 8 bits each. The device's cascaded feature allows up to four devices to share a common two-wire bus. The interface circuit of data store module is shown in Fig. 14.

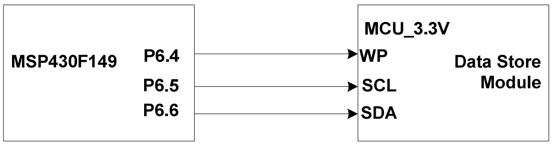


**Fig. 14.** Interface circuit of data store module.

### 3.3.4. Design of Software for the Intellectual Monitoring Node

This system is mainly designed using C language. The software main flow diagram of the system is shown in Fig. 15. The system need acquire real-time data of $CO_2$, wind speed, latitude and longitude, windward, height, humidity and temperature, etc. And it can display the related information in the on-site LCD, and send the information to the control central. Main flow diagram of the system shows Fig. 15.

The single-bus data format of DHT11 sensor is used for communication and synchronization between MCU and DHT11 sensor. It takes about 4 ms for one communication process. Data of temperature and humidity of the sensor consists of decimal and integral parts. The length of a complete data transmission is 40 bit, and the sensor sends higher data bit first. Data format of the sensor: 8 bit integral RH data + 8 bit decimal RH data + 8 bit integral T data + 8 bit decimal T data + 8bit check sum. If the data transmission is right, the check-sum should be the last 8 bit of "8 bit integral RH data + 8 bit decimal RH data + 8 bit integral T data + 8 bit decimal T data". Software flow diagram of DHT11 sensor is shown in Fig. 16.

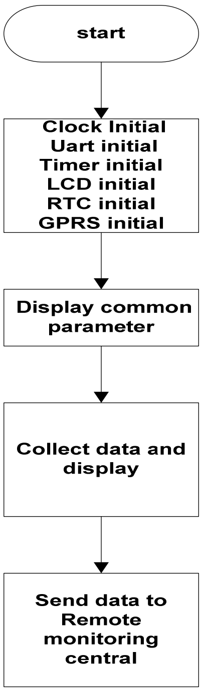


**Fig. 15.** Main flow diagram of the system.

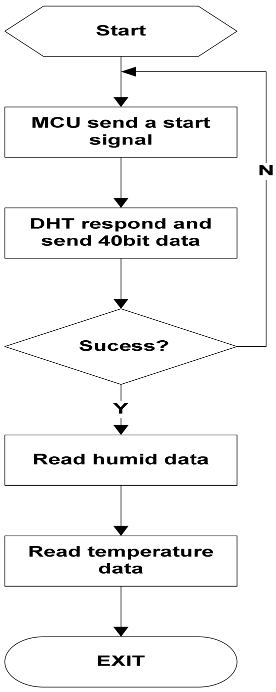


**Fig. 16.** Flow diagram of the DHT11 sensor.

Carbon dioxide sensor module B530 is currently the smallest and lightest $CO_2$ sensor module by using NDIR technology, and it can be widely applied to many fields, and can be used to control air quality for many devices. Data of $CO_2$ is collected by UART1 of MSP430F149 chip.

Communication between the intellectual node and the monitoring central is realized through wireless way by using GPRS module.

The initial flow diagram and the link flow diagram of GPRS module show in Fig. 17 and Fig. 18.

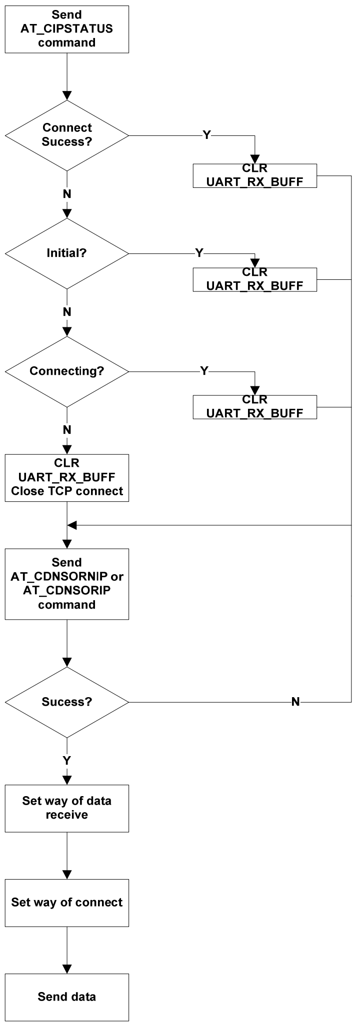


**Fig. 17.** Initial flow diagram of communication GPRS module.

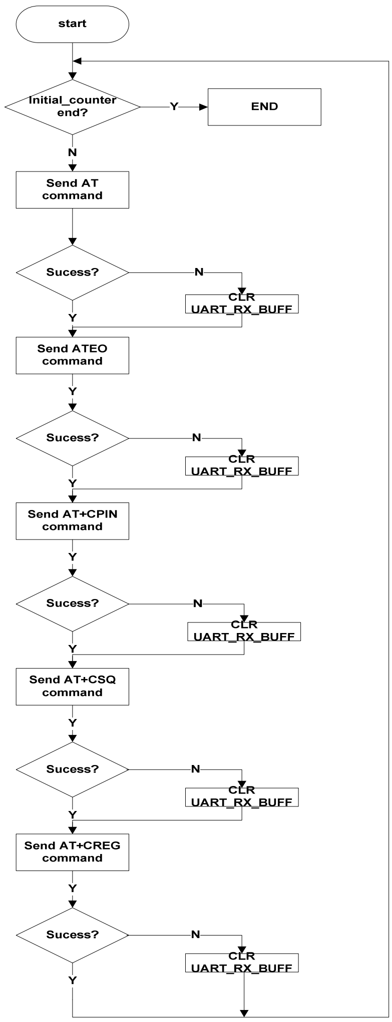


**Fig. 18.** Flow diagram of building link of GPRS module.

## 4. System Testing and Results

From May 2011 to the end of June 2011, we tested the $CO_2$ sinks in Taihu county, Zhejiang province of China. The actual system is shown in Fig. 19.

Its temperature measurement range is 0–50°C, and the corresponding accuracy is ±0.5°C; its humid measurement range is 0–95 %, and the corresponding accuracy is ±5 %.

In this experiment, we deployed ten nodes on the observing-field to monitor the parameters of environment in real-time and online. During this experiment, the range of temperature and humidity were 0-36°C and 45-95 %, respectively. We observed changes in the $CO_2$ range from between 375 ppm to 461 ppm (5m height which is distance from the ground), the maximum value appeared between 4 p.m.–6 p.m., and the minimum value appeared between 2 p.m.–4 p.m.


**Fig. 19.** Actual system.

The monitoring system can automatically collect the temperature, humidity and $CO_2$ of the environment once every other hour. Parameter values collected by the ten nodes should be transferred to the monitoring center via GPRS communication module. Fig. 20 is the daily changing curve of $CO_2$ in 5 m and 17 m, which is distance from the ground. Fig. 21 is the changing curve by using open-circuit eddy way in June, 2012.

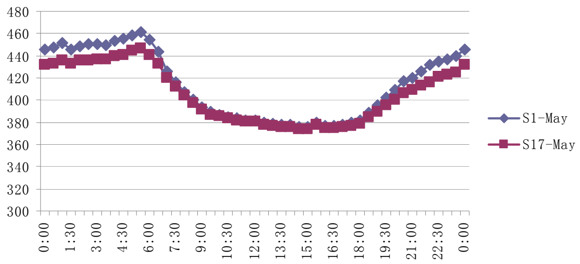


**Fig. 20 (a).** Curve of daily $CO_2$ changes monitored by the system in May 2011 (5.17 m).

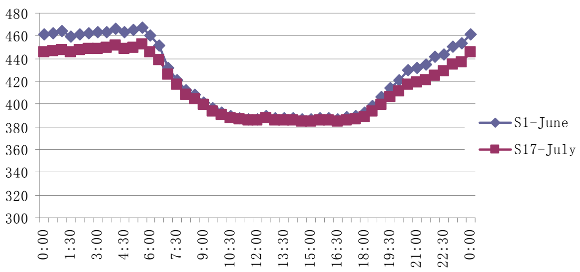


**Fig. 20 (b).** Curve of daily $CO_2$ changes monitored by the system in June 2011 (5.17 m).

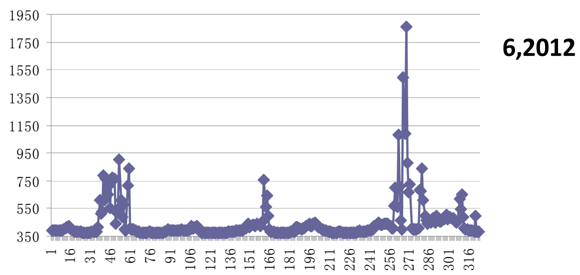


**Fig. 21 (a).** Curve of $CO_2$ changes monitored by the system (open-circuit eddy way).

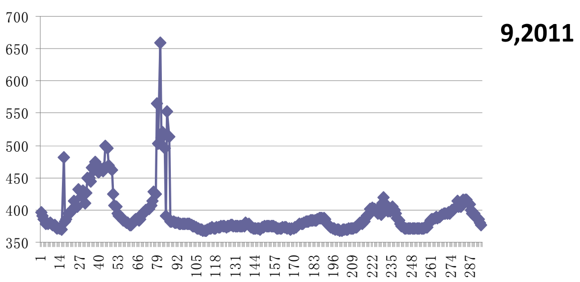


**Fig. 21 (b).** Curve of $CO_2$ changes monitored by the system (open-circuit eddy way).

It is perceptible in Fig. 20 that the maximum $CO_2$ value occurs between 4 p.m.–6 p.m. From the change of $CO_2$ in Fig. 21, $CO_2$ is influenced by the change of precipitation during a month and has been fluctuating within a certain range. But the changes each day were quite similar. In this experiment, by comparing $CO_2$ with that from the weather station once every other hour, the daily $CO_2$ are quite similar, which indicates the accurateness and reliability of the $CO_2$ detected by the monitoring system. In this experiment, coordinating with the monitoring system, the monitoring nodes have shown to be accurate and efficient in the remote and real-time detection on the $CO_2$ and humidity, temperature of the experiment area. It can provide support of base data for assess carbon budget of region-scale terrestrial ecosystems. Therefore, analytical processing of multidimensional data and assessment the regional carbon budget is an important work in the near future.

## 5. Conclusions

The monitoring system consists of two parts: intellectual monitoring nodes and remote monitoring center. It has some useful features such as large monitoring ranges and flexible configuration.

This paper is devoted to the explanation and illustration the monitoring system of carbon sinks based on a wireless network. The system is successfully applied for monitoring the carbon sinks in Taihu Town, Lin'an city, Zhejiang Province of China. Sensors applicable to different experimental parameters could be installed at the node to meet the monitoring demands in different region and to obtain different monitoring parameters. The monitoring system has important application prospects.

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