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Development of a solar wireless farmland environment monitor

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Abstract. According to farmland environmental factors which affect the crop growth, such as temperature, soil humidity, wind speed, wind direction and PM2.5 that has a greater impact on human's outdoor activities, a monitor has been put forward. The monitor takes Single Chip Microcomputer (SCM) as controller, combining sensor, AD converter, LCD display and wireless transceiver modules, etc, to realize real-time monitoring on farmland environment. To ensure the continuous operation of host system, the matching problem between solar panel and battery has been analyzed. Use solar controller to realize charge and discharge control between solar panel and battery, which has solved the problem of difficult power supply wiring in farmland. With burglar alarm and power-off protection against rain, ensure portable, safe and stable operation of the system. By interacting with the host controller, the slave controller provides real-time display of collected data, with maximum transmission distance of 1, 000m for open fields. In the same time, by communicating with host controller through RS232, the slave controller provides real-time display of environmental parameters through interface written by VC++. With advantages such as high collection precision and diversified functions, the system is significant to real-time monitoring on farmland environment.

Key words. Monitoring, SCM, solar, wireless transceiver, host-slave controller.

1. Introduction

In recent years, with continuous optimizing of agricultural planting structure in China, to raise crop yield and increase farmers' income entails realtime mastering change of farmland environment. The traditional sensor node depends on dry battery or utilizes single-phase alternating current for power supply after rectification, filtration and voltage stabilization. The former needs aperiodic replacement of cell, while the latter is troublesome in post-maintenance; the latter depends on power supply wiring, especially in rainy days, there is potential safety hazard [1, 2]. In this design, the single chip microcomputer serves as the controller, and storage battery serves as the energy storage element. Realtime monitoring of farm environment is realized by wireless transceiver module NRF24L01. The 12-bit 11-channel AD con-

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vertor TLC2543 adopted can facilitate expansion of other environmental parameters collection.

2. Analysis on system structure

This design is composed of host and slave. The host transforms, collects, processes, displays and transmits signals, while the slave receives, analyzes and displays data. Thereinto charge and discharge controller coordinates work of solar panel and storage battery. Soil humidity, wind velocity, wind direction and PM2.5 sensors convert non-electric quantity into electric quantity, and need to be converted into digital quantity in AD convertor, then processed in single chip microcomputer before display and transmission; The output of temperature sensor, infrared sensor and raindrop module is digital value with level standard being consistent with TTL level of single chip microcomputer, so they can be directly connected with single chip microcomputer; the alarm circuit mainly realizes the function of anti-theft alarm; the display circuit utilizes graphic LCD LCD12864 to display collected environmental parameters in real time; the wireless transceiver module enables data interaction between host and slave. The concrete structure is as shown in figure 1.

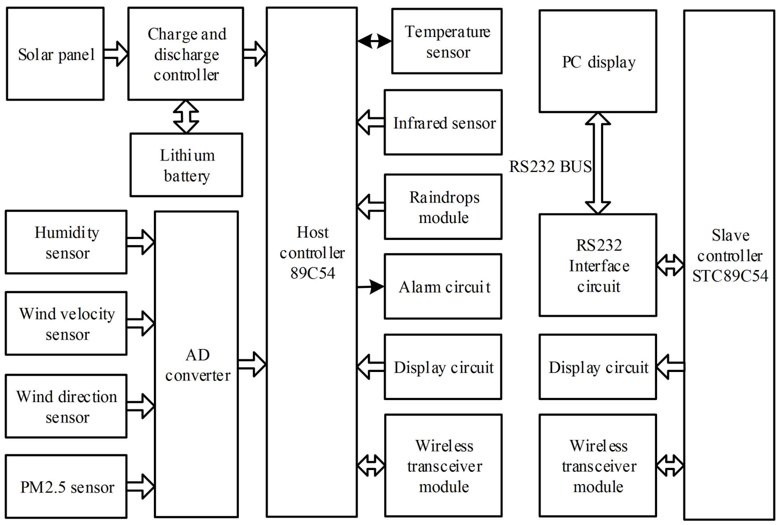

Fig. 1. System block diagram

3. Hardware circuit design

Control circuit is a circuit by which the host utilizes 89C54single chip microcomputer to process data and coordinates normal work of peripheral equipment. For solar panel and storage battery, charge and discharge controller enables overcharge protection and overdischarge protection for storage battery, and the solar panel will directly supply power to the system after the storage battery is fully charged [3, 4]; the relay is driven by transistor. A self-locking link is composed by key S1 and relay normally open contact. The on-off of normally open contact enables the system's power-off protection in rainy days. The drainage diode with relay coil reversely connected protects the driver from being damaged by surge voltage; three-terminal voltage stabilizer converts voltage of storage battery +12V into +5V needed by control circuit; NRF24L01 is single chip wireless transceiver module working at ISM wave band of 2.4 GHz $\sim$ 2.5 GHz. The highest transmission rate of 2Mbps can better match system's sampling rate [5–7]; LCD LCD12864 adopts series connection to economize I/O resource of single chip microcomputer; raindrop module judges whether it will rain according to the level fluctuation output according to conductibility of rainwater. DS18B20 is a bus-type digital temperature sensor with accuracy of $\pm$ 0.5 °C. Pyroelectric infrared sensor HC-SR501 has adjustable monitoring scope of 3 $\sim$ 7 m. Normal working of HC-SR501 has high requirements on power. The design utilizes three-terminal voltage stabilizer to supply power after filtration. The concrete circuit is as shown in figure 2.

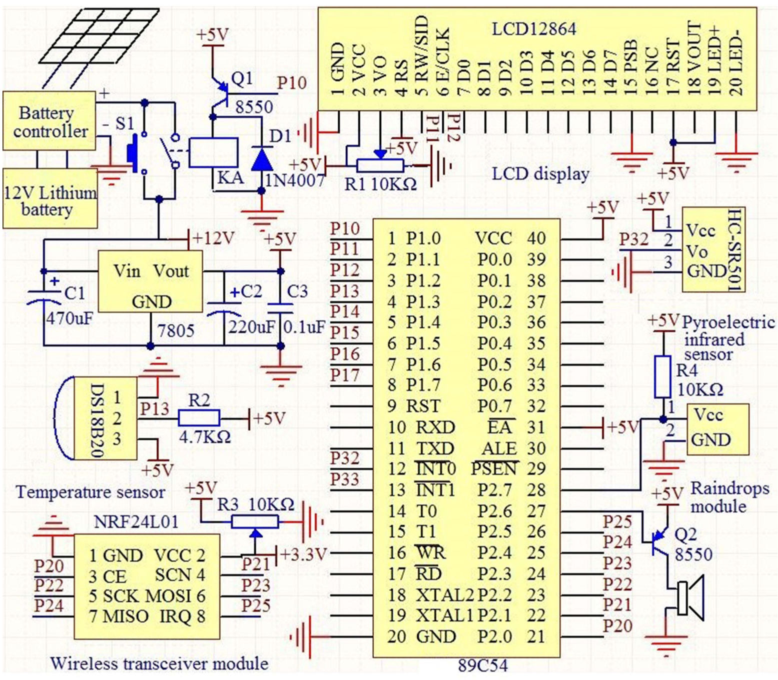

Fig. 2. Host data collection circuit diagram

LCD display circuit and wireless transceiver circuit of slave are the same with those of host. The difference is that slave can communicate with upper computer through RS232 interface circuit, and display environmental parameters on PC computer to realize human computer interaction. As single chip microcomputer is of TTL level, while RS232 bus is of RS232 level. To enable single chip microcomputer to communicate with upper computer through RS232 bus, level switch must be realized through RS232 interface circuit. The core device in RS232 interface circuit is MAX232 and interface circuit is a typical circuit [8, 9].

4. Matching of PV solar panel and storage battery

4.1. Selection of storage battery capacity

The function of storage battery is to supply electricity to host of environmental monitoring meter to maintain its normal working when solar irradiation is not sufficient in overcast days or night. Therefore the capacity of storage battery is closely related to local climate. According to standard of continuous overcast and rainy weather for agriculture and forestry industry, the capacity lasts at least for 3-5 days. Besides, to prolong battery life, some allowance is required when the storage battery is discharged to the end. As this system has power failure protection in rain, i.e. it only works in overcast days. The design selects 3 days for continuous discharging time of storage battery, and selects discharging depth as 90% [10, 11].

The current consumed by wind velocity and wind direction sensors is related to wind velocity and wind direction, being maximally 20 mA; other devices all adopt 5V power. Thereinto representative value of current consumption for PM2.5 sensor is 11 mA, and the maximum current consumption is 15 mA; consumed current of relay coil is 5 mA; the raindrop module is always in off-state without power consumed when it does not detect rain. If rain is detected, the relay contact is triggered to deenergize; the maximal consumed current of soil humidity sensor is 5 mA; when the wireless transceiver module NRF24L01's sending power is 6dBm in sending mode, the current consumption is 9 mA, and is 12.3 mA in receiving mode. The current consumption is even lower in power-fail or standby mode;

Work current of master controller 89C54 in normal mode is $4 \sim 8$ mA;output current of pyroelectric infrared sensor in static state is microampere level and it cooperates with alarm circuit in use. The power consumption is negligible when nobody triggers; the power consumption of temperature sensor DS18B20 is microampere level. The power consumption of LCD display circuit is great, but it is only applied to debug phase and displays environmental parameters in real time through slave. According to above analysis, the consumed maximal current when system works normally is about 86 mA. Battery capacity is figured out according to formula (1).

$$B_{li} = \frac{current\ output \times disch\arg e\ time}{disch\arg e} = 6880\,\mathrm{mAh}. \tag{1}$$

Select lithium battery with output voltage of 12 V, charge cut-off voltage of 12.3 V, discharge cut-off voltage of 9 V and battery capacity of 7000 mAh.

4.2. Selection of solar panel capacity

Installation azimuth, inclination and superficial cleanliness of solar panel have important effect on the solar irradiation received by it. The design uses formula (2) to calculate output power of battery. According to average peak sunshine hours of 3.6h in local climate, loss coefficient is between 1.6 $\sim$ 2.0 [12] and this design takes loss coefficient of 1.6:

$$P_S = \frac{load\ power \times load\ working \text{ hours}}{average\ peak\ sunshine \text{ hours}} \times loss\ coefficient \approx 7.6\text{W}. \tag{2}$$

As the charge and discharge efficiency of lithium battery is smaller than 1, plus the lithium battery has energy self-leakage, to realize cyclic charging and discharging of lithium battery, from the perspective of energy consumption, set the solar power collected by host system within time T as Ps (t), PL (t) is the energy consumed during this period, then formula (3)must be met to make the system work in a cyclic way.

$$B_0 + \eta \int_o^T P_S\,(t)\,dt - \int_0^T P_L\,(t)dt \geq B_1. \tag{3}$$

Where, B_0 is the initial value before lithium battery is not charged, η is charging efficiency of lithium battery, B_1 is the lithium battery's energy before next charge cycle when $t = T$. Simplify the above formulas to get formula (4).

$$\frac{1}{T} \int_0^T P_S\,(t)dt \geq \frac{1}{\eta} \left[\frac{B_1 - B_0}{T} + \frac{1}{T} \int_0^T P_L\,(t)\,dt \right]. \tag{4}$$

As the average value of solar power collected within charge and discharge cycle T is formula (5).

$$P_S = \frac{1}{T} \int_0^T P_S\,(t)\,dt. \tag{5}$$

The average value of energy consumed by host within cycle T is formula (6).

$$P_L = \frac{1}{T} \int_0^T P_L\,(t)\,dt. \tag{6}$$

Substitute formula (5) and (6) into (4) to get formula (7).

$$P_S \geq \frac{1}{\eta} \left(\frac{B_1 - B_0}{T} + P_L \right). \tag{7}$$

The calculation result of formula should also guarantee continuous running of the system, and must meet formula (7) [13]. Considering the extreme cases, charge and discharge cycle T is 24 h, initial value of B_0 is 0, PL $= 12 \times 40 + 5 \times 47.3 = 716.5$ mW. Take discharging depth of cycle charging as 10%, then $B_1 = 7 \times 12 \times$ (1-10%) = 75.6 Wh, substitute it into formula (7) to get: Ps $\geq$ 4.3 W. the condition of host's continuous working is met. The design selects polycrystal solar panel with power of 10 W, charging voltage of 12 V, peak current and short circuit current of 0.56 A and 0.61 A respectively. The installation inclination is 45°.

5. Software design

Main program is the entry of program and the hinge that coordinates subprogram at each data collection port, wireless transceiver subprogram and display subprogram. After the system is electrified, initialize the subprogram and monitor the interface of sing chip microcomputer in real time. While the host transmits the collected digital signal to slave, the digital signal is converted into concrete unit measurement value of the measured object after scale transformation, and the host invokes display subprogram for real-time display. The concrete flowchart is as shown in figure 3.

LCD displays concrete PM2.5 concentration, air quality and notices for outgoing [14, 15]. The design of slave software is similar to host, but slave simplifies data collection subprogram, and just receives the data sent by host.

6. System test and problem analysis

6.1. System test

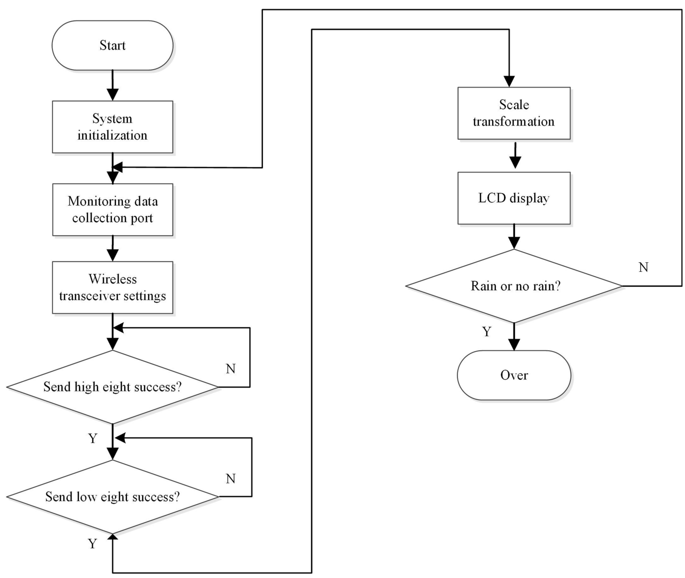

Fig. 3. Main program flowchart

Lower computer subjects the data sent by host to scale transformation before real-time display on LCD. Meanwhile lower computer displays environmental parameters on upper computer through RS232 bus. The interface of upper computer is compiled using MSComm communication control provided by VC++. MSComm control provides perfect function of serial port data transmission and receiving, and it essentially invokes API function. The design adopts event driven mode: the OnComm event of MSComm control collects and processes communication errors and events. Baud rate is 9600 [16].

The concrete experiment is tested in agricultural demonstration garden: save the data collected by upper computer once every 1 hour. The air temperature, soil humidity, wind velocity, wind direction and PM2.5 collected on the hour from 8: 00 to 15: 00 in one day are as shown in table 1.

Table 1. Environmental monitoring data

Air temperature (°C)	Soil moisture (%RH)	Wind speed (m/s)	Wind direction	PM2.5 concentration (μ g/m ^{3})
4	52.5	3	Northwest	42
6	52.5	3.3	Northwest	45
7.5	51.5	3	Northwest	45
9.5	50	2.5	Northwest	62
12	50	3.5	Northwest	68
14	48	4	Northwest	58
17	47	3	Northwest	60
16.5	47	4	Northwest	59

As the measurement accuracy of sensor is high, the air temperature, soil humidity, wind velocity and wind direction are basically consistent with standard measurement value.

6.2. Problem analysis in the debugging course

6.2.1. Data collection result is wrong. The read-write operation of TLC2543 by single chip microcomputer must strictly abide by its time sequential routine, or sequential routine is disordered, leading to inability of AD convertor to work normally.

6.2.2. The realtimeliness of host for data collection system is weak. The display of environmental parameters on host lags by about 2s, as there are three operate modes of timelag waiting, query and interruption for single chip microcomputer to control AD converter TLC2543. In early period of design, timelag waiting is adopted. Too long time delay interval in AD conversion for each channel results in display lagging. While query or interruption mode needs to judge TLC2543's pin 19 EOC. After AD conversion ends, EOC outputs high impulse, while interruption of 89C54 single chip microcomputer is triggered by low level. Negater needs to be added to EOC output end, thereby complicating hardware. The query mode can economize hardware resource and improve system realtimeliness. The real object of host is as shown in figure 4.

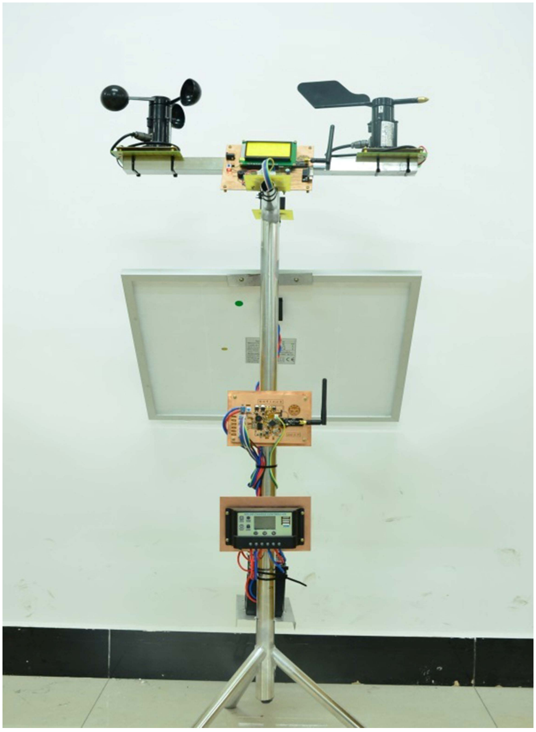

Fig. 4. Host physical map

7. Conclusion

The paper introduced structure analysis of solar wireless environmental monitoring meter applied in agricultural domain, hardware design, software design and system debug, etc, fabricated and debugged real object, summarized the problems encountered in debugging and the solution, which is of certain reference significance to this type of design. To guarantee system's sustainable operation, the power of solar panel, influencing factors and capacity of storage battery are designed reasonably, laying a firm base for subsequent using network processing unit CC3200 with built-in Wi-Fi to replace the single chip microcomputer applied in this design and using internet and cloud platform cooperation.

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