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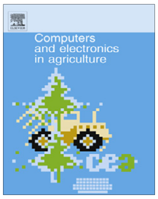

Real-time monitoring system for paddy environmental information based on DC powerline communication technology

Ying Huang *, Cuicui Li

Liuzhou Railway Vocational Technical College, Liuzhou, Guangxi, China

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ABSTRACT

In view of the characteristics of a long monitoring period, great environmental interference, slow acquisition speed and lack of automated management in the process of farmland environmental data collection, an innovative approach to monitor paddy environmental information based on DC powerline communication technology was proposed. It analyzes in detail the composition structure. Circuit schematics are designed, and working principles are elaborated; a system program and PC monitoring software are also designed. The system was composed of slave nodes; a master node to collect data from the slave nodes; one server installed on a PC to retrieve, store and present the data; and monitoring software that can present the data via a browser. A communication protocol is adopted to collect data form more slave nodes, and WebSocket and vector markup language (VML) are applied for monitoring software design. Communication distance experimental results indicated that the communication distance can be extended to 3000 m with power of 36 V DC. The accuracy and loss rate experimental results showed that all nodes' accuracy is higher than 98%. The system test results showed that the average relative errors of air temperature, air humidity and soil moisture are 0.39%, 0.31% and 0.64%, respectively.

1. Introduction

Appropriate temperature, humidity and soil moisture play important roles in grain yield and quality. To improve rice yield and efficiency, it is necessary to monitor paddy environmental information. In view of the characteristics of long monitoring periods and field monitoring, wireless sensor networks are widely used for monitoring paddy environmental information. In wireless data monitoring, wireless sensor networks show superiority but also have drawbacks. In the wireless transmission process, the transmission speed, transmission distance and transmission quality are limited by the installation location and affected by obstacles. In addition, wireless sensor networks require complex routing or algorithms to complete data monitoring. Therefore, data loss, data inaccuracy and unreliable transmission occur frequently in the data transmission process. To improve data transmission distance, transmission rate and transmission quality, powerline communication technology is adopted in this system. Powerline communication technology, which can send both power and data between slave nodes in a half-duplex manner, offers a cost-effective communication medium for a wide range of applications in environmental monitoring, especially for field monitoring (Sung et al., 2015; Ajinder Singh and Dave Hermann, 2014). Powerline communication can be divided into two types: direct current (DC) powerline communication and alternating current (AC) powerline communication (Sung et al., 2015; Zhuochao Sun, 2010). AC powerline communication has been the focus of attention by researchers, and AC powerline communication technology is relatively mature. In contrast, the DC powerline communication technique, which is suited for many applications (e.g., home security, DC buildings) is still in the beginning phase and has aroused the interest of researchers in recent years. DC powerline communication can reduce cable requirements and has proven to be a useful and economically viable technology (Hines, 2000; Strassberg, 1996). A wired protocol employing powerlines as communication buses (Ferreira et al., 1996) and PLC is adopted to efficiently integrate monitoring systems into Smart Grids (Galli et al., 2010; Ipakchi and Albuyeh, 2009). Powerline communication has been widely used in practice; the most well-known and the largest PLC network was developed by the Italian electricity company (Giordano et al., 2011). To make powerlines work effectively in a given system, the system impedance should be time invariant, and noise from power supplies should be filtered (Hailu et al., 2014). In view of the characteristics of long monitoring periods, great environmental interference, slow acquisition speed and lack

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* Corresponding author.
E-mail addresses: 18978225815@163.com (Y. Huang), 18978225815@163.com (C. Li).

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of automated management in the process of monitoring, a real-time paddy information monitoring system based on DC powerline communication technology was designed. This contribution focuses on the composition structure, the hardware design and the software design of the system and presents the master and slave modules design, and a protocol is chosen as a solution for transmitting information between slaves and master modules. Finally, the PC terminal is also designed to achieve remote monitoring.

2. System structure

The proposed system consists of five parts: solar-powered module, master node, slave nodes, coordinator node and mobile terminal. The solar power module is used to charge the battery and supply power for the master node and slaves nodes. The solar power module mainly comprises solar panels, a charging protection circuit and a battery. The solar-powered module structure is shown in Fig. 1.

The master node, comprising a processor module and GPRS module, is responsible for collecting data sent from each slave and sending them over the network module to the user terminal module for processing and display (Feng et al., 2014; Pan et al., 2014). Slaves mainly include a processor module and sensor module and are responsible for collecting environmental information and sending it to the master via a square wave bus. Information is transmitted between slaves and master modules over existing power cables in a half-duplex manner. This concept is represented in Fig. 2.

To improve the transmission distance, increase the number of connected slaves and improve the anti-jamming capability, the RS485 interface is used for the master and slave. Another advantage of the RS485 interface is its ease of expanding the installation.

3. Hardware design

3.1. Solar-powered module diagram

The solar-powered module provides continuous power for the system. The solar-powered module diagram is shown in Fig. 3.

The solar panels' maximum short-circuit current is 500 mA and the open-circuit voltage is 18 V. Because the rechargeable battery is +24 V, to ensure the charging effect in accordance with a voltage factor of 1.5, that is, 36 V, two +18 V solar panels connected in series are required. Solar powers from solar cells charge the battery through a 1N5818 Schottky diode. The 1N5818 diode allows a charging current to flow into the photovoltaic cell during the charging process but only at night to prevent reverse current flow into the regulator circuit. There is no sunlight at night, so there is no voltage at either end of the solar cells; then, the he battery provides power to other circuits. The 1N5818 diode has unidirectional conductivity, so it can prevent reverse current flow into the regulator circuit and play a protective role in the circuit. In addition, it has a lower forward voltage drop (approximately 0.4 V), which is the efficiency of the circuit. The regulation point of the TL431AC chip is 2.5 V, which can be calculated by dividing circuits R5, R4 and R3. The input voltage of the TL431AC can be obtained by the following formula (1).

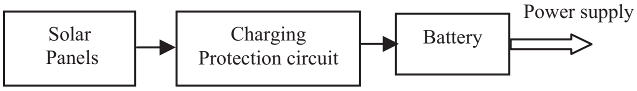

Fig. 1. Solar-powered module structure.

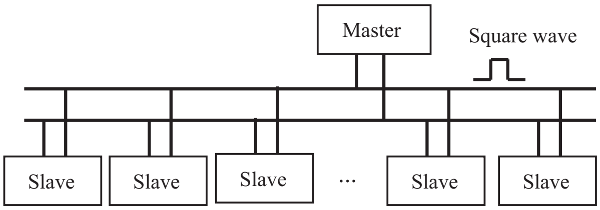

Fig. 2. Block diagram of system.

$$V_{input-TL431AC} = \frac{R5 + R_x}{R5 + R4 + R3} \times BAT_{\max} \quad (1)$$

where R_x is over the potentiometer R4, and BAT_{max} is the maximum value of the battery voltage, which can be obtained from the technical manual. Typically, the +24 V battery voltage range is 19.2–27.6 V, so we use 27.6 V. When the battery voltage rises to the regulation point of the TL431AC, the TIP30B transistor starts conducting. When the TIP30B transistor conducts, its turn-on voltage is approximately 1 V, so the value of R1 can be calculated by formula (2).

$$R_1 = \frac{BAT_{\text{Nominal value}} - 1}{I_{\max}} \quad (2)$$

where $BAT_{\text{Nominal value}}$ is the nominal value of the battery voltage, which is +24 V, and I_{max} is the solar panel maximum short-circuit current (500 mA).

Thus, the value of R1 is 46 Ω, and the TIP30B and R1 connected to both ends of the photovoltaic panels transfer the excessive charging current via the load to maintain a constant voltage. The power consumption of R1 can be calculated by formula (3).

$$P_{R_1} = I_{\max}^2 \times R_1 = (0.5\ \text{A})^2 * 46\ \text{ohm} = 11.5\ \text{W} \quad (3)$$

When the battery reaches the float setpoint, the charging control circuit will consume all solar power. When the solar cell output current reaches 500 mA, the TIP30B transistor and a load resistor (R1) will produce high temperature. According to that formula (3), the power of R1 will reach 11.5 W. R1 will burn out at a sustained high-temperature state. To ensure that R1 does not burn out in the working state, R1 can instead be implemented as five 220 Ω resistors (5 W). In addition, the heatsink should be installed.

The solar-powered module requires calibration before use. The solar cells and +24 V battery are connected to the circuit, and then the R2 (20 K potentiometer) is adjusted until the TIP30B transistor is turned on.

To provide power for the microcontroller circuit, sensor circuit, GPRS module circuit, etc., a regulator circuit is designed. The regulator circuit diagram is shown in Fig. 4.

Voltages of +12 V and +5 V are achieved by an LM2575HVS-12. DC voltage of +24 V is input to the input terminal regulator chip LM2575HVS-12. After filtering, the output terminal can produce high accuracy, stability and good DC output voltage. LED0 is used to indicate the status of the circuit. After the circuit is powered, the indicator will light.

3.2. Temperature and humidity sensor DHT11 circuit

The DHT11, using a dedicated digital module collection technology and temperature and humidity sensor technology, is the integration of a digital wet temperature sensor and has high reliability and stability. We can use simple single-bus communication between DHT11 and SCM. DHT11 works under 5 V supply voltage and has an average maximum current of 0.5 mA. It has precision of ±5% humidity and ±2 °C temperature and resolution of 1% humidity and 1 °C temperature. The DHT11 temperature and humidity sensor diagram is shown in Fig. 5.