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Design of a Solar-Powered Label for Animal Husbandry Information Monitoring

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Abstract

To reduce energy consumption and enable energy-efficient remote livestock monitoring, photovoltaic self-powering represents a viable solution. This study implements an information monitoring and transmission system through device selection, low-power design, and optimization of photovoltaic self-power circuitry. Cloud platform integration was achieved using MQTT Protocol. Experimental results demonstrate the system collects temperature, humidity, and triaxial acceleration data every 4 seconds while transmitting Bluetooth broadcasts at 1Hz. The average operating current measures 9.78 μA. Energy storage via a 220μF capacitor sustains system operation for approximately 26.5 seconds under low-light conditions, with discharge duration exhibiting linear proportionality to capacitance value.

Keywords

Photovoltaic self-power supply; Low power consumption; Enhanced device protocol; Remote monitoring; Livestock information.

1.Introduction

With the deep integration of modern information technology and animal husbandry, the digital transformation of large-scale farms through IoT and big data is accelerating. Information monitoring of breeding environments, livestock behaviors, and physiological status has provided scientific foundations for precision farming [1-3]. Compared with traditional breeding models, the introduction of information monitoring systems significantly promotes scientific, intelligent, and scaled livestock management.

Current research has developed various livestock monitoring systems, with particular emphasis on environmental monitoring. Yang et al. designed a Raspberry Pi-based system for monitoring air temperature/humidity, illumination, and video feeds, though it suffers from high power consumption and inconvenient power supply despite its powerful processor [4]. Han et al. implemented General Packet Radio Service (GPRS)-based Data Transmission Units (DTUs) for remote monitoring via

Ethernet, yet faced challenges with high startup currents in GPRS modules [1]. Huang et al. employed low-power Narrowband IoT (NB-IoT) modules with Constrained Application Protocol (CoAP) optimization, though lacking dedicated power-saving designs [5]. Beyond environmental monitoring, real-time tracking of livestock behaviors and status proves crucial for breeding quality enhancement. Zhang et al. developed implantable RFID temperature-sensing chips for porcine body temperature and water intake monitoring, enabling early disease warnings [6]. With advances in machine learning, video-based behavioral analysis has gradually been applied in commercial farming [7]. Liu et al. created a cow pedometer system using STM32 and OneNET cloud platform for estrus detection [8], while Wang et al. further analyzed detailed behaviors like standing and feeding through fuzzy clustering of accelerometer data [9]. These contactless technologies demonstrate practical viability for animal behavior monitoring.

Existing studies provide valuable insights, yet practical constraints remain: Wired systems prove unsuitable for mobile livestock due to installation difficulties, while wireless alternatives face power supply challenges. Frequent battery replacement in large-scale farms incurs high costs, environmental concerns, and operational burdens. Self-powered technology integrated with ultra-low-power circuits presents the most suitable solution for such scenarios.

This study focuses on monitoring both breeding environments and livestock behaviors, addressing practical requirements for self-powering and mobile low-power monitoring nodes. The system employs Bluetooth Low Energy technology to aggregate data at gateways, which subsequently transmit information to cloud platforms via Device Enhancement Protocol. Through comprehensive testing of self-powering performance and system power consumption, we provide guidelines for optimized field deployment.

2.Hardware structure design

2.1.Overall Design

The system comprises three components: sensor nodes, base stations, and the OneNET cloud platform. Each node integrates the following subsystems: signal acquisition unit, photovoltaic self-powering unit and control module. Signal acquisition unit combines a triaxial accelerometer, temperature and peripheral circuits. Photovoltaic self-powering unit provides autonomous energy supply. Control module features Atmosic's system-on-chip (SoC) ATM3202, which incorporates an ultra-low-power microcontroller unit, embedded bluetooth low energy (BLE) protocol stack.

As shown in Figure 1, the ATM3202 communicates with sensors via I^2C interfaces, performing three critical functions. Acquires environmental parameters and triaxial acceleration data processes raw accelerometer outputs into quantifiable animal movement metrics. Transmits compiled environment/motion data to base stations via BLE. Base stations then forward the information to China Mobile's OneNET public cloud platform using the MQTT format.

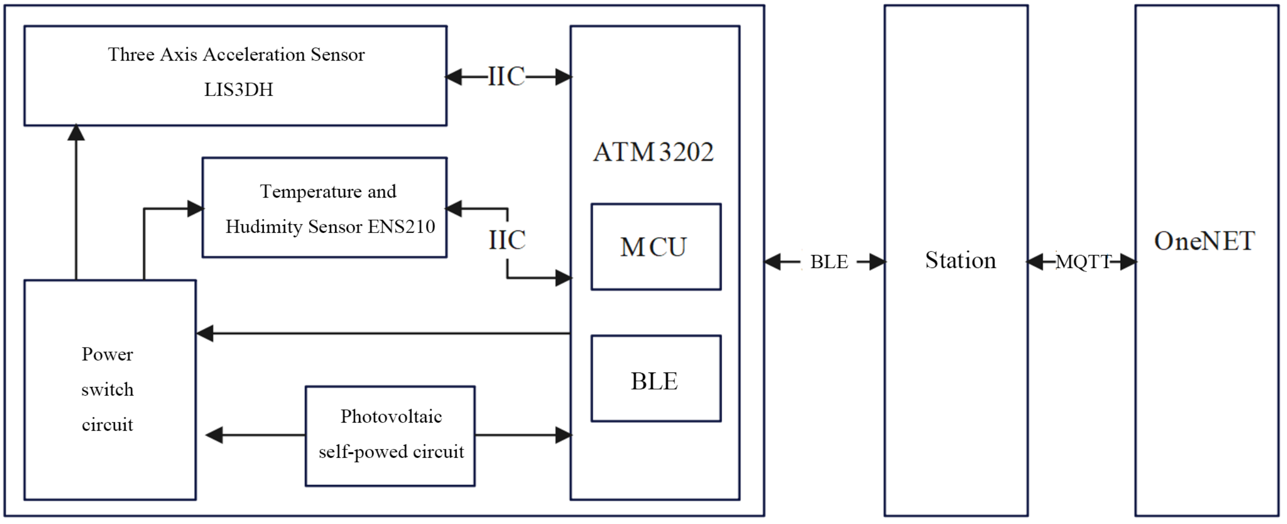


Figure 1: System structure diagram

The node system is powered by a photovoltaic self-powered circuit. Since environmental illumination cannot be guaranteed during operation, energy storage devices are added for energy storage. Considering the limited storage capacity of energy storage components, system parameter optimization and low-power design are employed to enhance energy storage efficiency during the charging process while extending the energy release duration of the storage components under low-light conditions, ensuring that the energy provided by the storage devices meets the normal operation requirements of the system.

2.2.Low-Power Hardware Design

To meet the application requirements of low power consumption and compact size for livestock wearables, this design is optimized through component selection, power switching circuits, and self-powered circuits.

2.2.1 Component Selection

The system's power consumption primarily originates from the MCU, sensors, and communication modules.

An SoC solution integrating MCU and communication functions is preferred for low power consumption and miniaturization. This study selects the ultra-low-power ATM3202 module, which features an ARM Cortex-M0 core, Bluetooth 5.0, and an energy management unit. It operates at a typical voltage of 3V and supports multiple low-power modes.The current is 0.8μA in the sleep mode and 2μA in the Retention mode. During Bluetooth operation, power consumption increases. The average current is 1mA in receive mode and 2.5mA in the transmit mode.

The module supports energy harvesting from RF, light, thermal, and vibration sources. Harvested energy is stabilized via an internal energy management unit and low-dropout regulator (LDO).

The triaxial accelerometer employs STMicroelectronics' LIS3DH, featuring ultra-low power consumption with 11μA operating current and 2μA in low-power mode. The voltage has a wide range which is from 1.71V to 3.6V. The ENS210 sensor operates at 1.71V–3.6V with a 1Hz sampling rate, consuming 6.6μA in active status and 0.04μA in standby status. Both sensors function effectively at low voltages.

With these components, the system's quiescent current remains in the μA range.

2.2.2 Power Switching Circuit

When the sensor is not working, there is still current, which consumes energy. By adding a power switch circuit without external power supply, the system power consumption can be reduced. The power switch circuit is shown in Figure 2, and the input voltage VIN comes from the output voltage of the self powered circuit, providing a stable 3.3V power supply; The output voltage of the power switch circuit is a 3.3V voltage VOUT controlled by the P11 switch signal, which supplies power to the sensor. When the switch signal is low, the P-type MOS transistor Q2 opens and outputs a voltage of 3.3V; When the switch signal is high, the MOS transistor is turned off and does not consume battery power. Compared with traditional power switch circuits, this circuit has a simple structure and is suitable for application in small-sized intelligent systems.

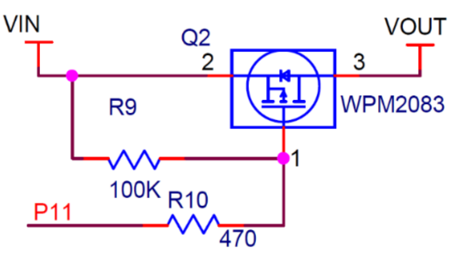


Figure 2: Power switch circuit

2.2.3 Self-Powered Circuit Design

The selected ATM3202 module integrates an internal energy management unit. As shown in Figure 3, the photovoltaic panel output voltage is connected to the MCU module's HARV_OUT pin through a Schottky diode. The internal processing unit manages the photovoltaic voltage and allocates energy. When illumination is strong, part of the energy supplies system operation, while excess energy is output through the VSTORE pin. The VSTORE pin is connected to ground via capacitor C1, storing surplus energy across C1. When external illumination energy is insufficient to support system operation, the stored energy in C1 is utilized to meet operational requirements.

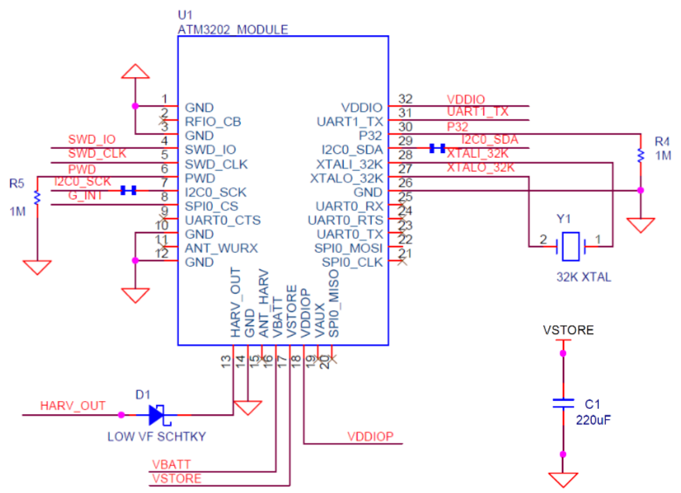
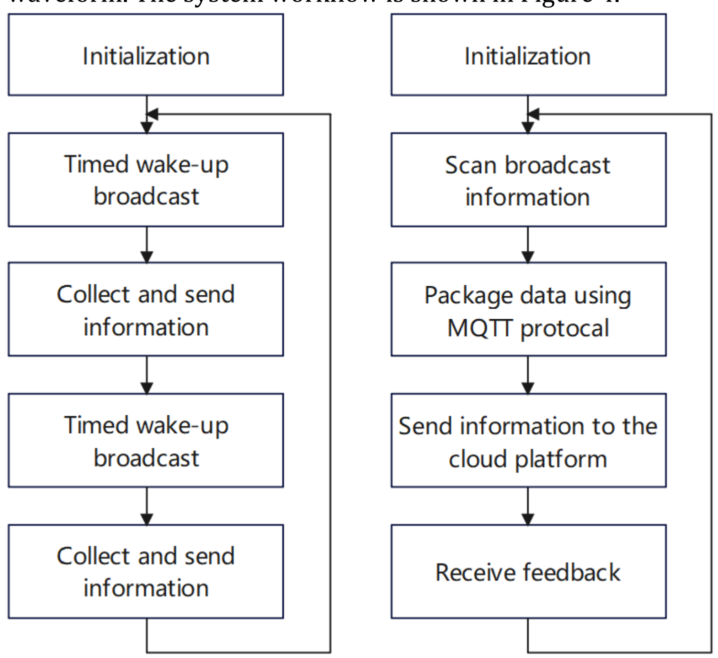


Figure 3: Photovoltaic self power supply circuit

3. Low power software design

To further reduce power consumption, this article uses a regular Bluetooth broadcast mode to reduce communication time and optimize the system's operating waveform. The system workflow is shown in Figure 4.



(a) Node workflow **(b)** Gateway workflow

Figure 4: System workflow

The system is mostly in sleep mode, with sensors turned off and the MCU in ultra-low power consumption mode; Automatically wake up at a frequency of 1Hz and send Bluetooth broadcasts to the outside; Every 4 seconds, the MCU controls the sensor to work, collecting environmental temperature and humidity, livestock and poultry behavior information once, and sending the information to the gateway through Bluetooth broadcast. The duration of work is determined by the device. In this working mode, the average working current is less than 10 μ A; Once the gateway scans the broadcast signal, it will be grouped according to the MQTT protocol's grouping rules and transmitted to the cloud platform.

When obtaining livestock and poultry behavior information, the MCU collects three-axis acceleration information in the forward, longitudinal, and lateral directions. Considering the power consumption of the node system, the analysis of three-axis acceleration information is placed on gateways or servers with strong computing power and low power consumption requirements to obtain livestock behavior information such as steps and behavior patterns [9,10]. Process the three-axis acceleration using the 2-norm method to obtain accurate acceleration [10], and compare the acceleration with a threshold. If the acceleration exceeds the threshold, add 1 step; Analyze the posture of poultry and livestock through fuzzy clustering algorithm [9].

The gateway needs to exchange information with the cloud platform according to a certain application layer protocol, and the choice of application layer protocol directly affects system reliability, power consumption, and other performance. Considering the low power consumption and limited resources of IoT devices, lightweight protocols such as Message Queuing Telemetry Transmission (MQTT), Constrained Application Protocol (CoAP) and et,al have been specifically developed.

4.Conclusions

This article designs a remote monitoring system for livestock information based on photovoltaic self power supply. To ensure the normal operation of the system without external power supply, the system has been optimized and designed. By selecting and testing external energy storage components, the relationship between self powered working time, capacitance value, and working current has been clarified. Select a series of low-power devices, design switch circuits, optimize working waveforms, and other methods to achieve low-power information acquisition and transmission, further extending the self powered working time under low ambient light conditions. The test results show that when the voltage exceeds 1.75V, it can drive the MCU to start working normally; Using a cycle of 4 seconds, the system collects temperature and humidity values as well as three-axis acceleration values once. Bluetooth sends out broadcasts at a frequency of 1 Hz, and the average power consumption of the system is about 9.78 μ A; The photovoltaic self powered circuit using 220 μ F capacitors for energy storage can maintain system operation for 26.5 seconds in low light environments. By optimizing the design of the remote monitoring system for livestock information, it provides support for further promoting the energy-saving digital transformation of poultry and livestock farming, and also prepares technical reserves for scientific breeding.

Acknowledgements

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