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A Wildlife Monitoring System Based on Wireless Image Sensor Networks

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Abstract: Survival and development of wildlife sustains the balance and stability of the entire ecosystem. Wildlife monitoring can provide lots of information such as wildlife species, quantity, habits, quality of life and habitat conditions, to help researchers grasp the status and dynamics of wildlife resources, and to provide basis for the effective protection, sustainable use, and scientific management of wildlife resources. Wildlife monitoring is the foundation of wildlife protection and management. Wireless Sensor Networks (WSN) technology has become the most popular technology in the field of information. With advance of the CMOS image sensor technology, wireless sensor networks combined with image sensors, namely Wireless Image Sensor Networks (WISN) technology, has emerged as an alternative in monitoring applications. Monitoring wildlife is one of its most promising applications. In this paper, system architecture of the wildlife monitoring system based on the wireless image sensor networks was presented to overcome the shortcomings of the traditional monitoring methods. Specifically, some key issues including design of wireless image sensor nodes and software process design have been studied and presented. A self-powered rotatable wireless infrared image sensor node based on ARM and an aggregation node designed for large amounts of data were developed. In addition, their corresponding software was designed. The proposed system is able to monitor wildlife accurately, automatically, and remotely in all-weather condition, which lays foundations for applications of wireless image sensor networks in wildlife monitoring. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Wildlife monitoring system, Wireless image sensor networks, System architecture, Node design, Software process design.

1. Introduction

Survival and development of wildlife sustains the balance and stability of the entire ecosystem. Wildlife monitoring can provide a wealth of information such as wildlife species, quantity, habits, quality of life and habitat conditions, to help researchers grasp the status and dynamics of wildlife resources, and to provide basis for effective protection, sustainable use as well as scientific management of wildlife resources. Traditional wildlife monitoring methods (e.g., [1-5]) have been extensively explored in monitoring applications. However, they all have limitations.

Here, we overview some of the traditional wildlife monitoring methods.

First is artificial field survey including linear intercept method, fixed-point notation, meet rate method, and questionnaire [1]. It is limited in scope of monitoring, labor-intensive, high-risk and cannot achieve all-weather monitoring. Second is a global positioning system (GPS) collar. Compared with traditional radio collars, GPS collars can provide better spatial resolution and determine the location in broader temporal and spatial conditions [2-3]. However, this monitoring method is not able to obtain image information of animals. The third method employs infrared cameras. The image data taken from infrared cameras are stored in the local large-capacity SD memory card. At a certain time interval, researchers have to go to the scene to remove the SD card and read the data [4]. This approach has many drawbacks such as lagged data collection, long monitoring cycle, high labor intensity, high risk, etc. Some infrared cameras connected with 3G networks can send the image data to the user's mobile phone through 3G networks. This method relies on the coverage of 3G mobile phone signal, and the core area of some national nature reserves is not covered by mobile phone signal. The fourth method uses wireless cameras to transmit images through wireless broadband microwave. Due to the necessity of power supply and high deployment, obtaining images of wildlife forest activities is difficult and the equipment cost is relatively high. The fifth method is satellite remote sensing [5]. Satellite remote sensing integrated monitoring is difficult to accurately measure the local microscopic information due to the spatial resolution. In addition, satellite remote sensing cannot provide real-time monitoring since it has scan cycle.

Wireless sensor networks (WSNs) consist of thousands of cost-effective miniature sensor nodes capable of computation, communication and sensing [6]. WSNs can overcome the shortcomings of the traditional monitoring methods and have provided tremendous benefit for applications such as forest fire monitoring, nature biodiversity monitoring, timber detection and forest ecology [7-12]. With the advancement in CMOS image sensor technology, wireless sensor networks combined with image sensors, namely wireless image sensor networks (WISNs), have recently come into prominence since they can provide visual monitoring of effects in the environment. In this paper, we propose a wildlife monitoring system based on WISNs. In essence, the major contribution of this paper involves general system architecture of the wildlife monitoring system based on WISNs and the hardware and software design of the system. The proposed system is able to monitor wildlife accurately, automatically, and remotely in all-weather condition.

The rest of the paper is organized as follows. In Section 2, an overview of WISNs is presented. In Section 3, the proposed wildlife monitoring system based on WISNs is stated. The hardware and software design of the monitoring system is described in Section 4 and Section 5, respectively. Finally, some conclusion remarks are made in Section 6.

2. Wireless Image Sensor Networks

WSNs, combine sensors, embedded systems and wireless communication technology, have a wide range of potential applications due to their advantages including self-organization, adaptive capacity, data-centric, application-specific, small size, low cost and wide area monitoring capability. WSN technology is also an important branch of the Internet of Things [13]. WSNs have increasingly being used in the military, space exploration, environmental monitoring, home health care, disaster prevention and other areas [14]. WSNs mainly collect simple physical information such as light and temperature leading to a small amount of data. However, with the advancement of the CMOS image sensor technology, it is possible to integrate small, low power, and cost-effective image sensors to WSNs. The resulted WISNs are able to collect valuable visual information of the target object and its surroundings. Wildlife monitoring is one of the most promising applications of WISNs [15]. WISNs can collect image information and realize wireless remote transmission to achieve real-time, fine-grained, and precise wildlife monitoring [16].

3. Wildlife Monitoring System Based on WISNs

Cervus elaphus is a second class national-level protected animal due to excessive cubs hunting and habitat loss. Inner Mongolia is one of the main Cervus elaphus distribution areas. This paper chooses wild Cervus elaphus in Inner Mongolia Saihanwula as the object to carry out the research of wildlife monitoring using WISNs. The monitoring system based on WISNs includes a wireless infrared image sensor network, a base station and a wildlife monitoring center. The overall architecture of the wildlife monitoring system based on WISNs is shown in Fig. 1.

A WISN consists of many infrared image sensor nodes deployed in wildlife activity areas or nearby areas and a sink node. Infrared image sensor nodes usually lie dormant. Once a wild animal enters the detection zone, the pyroelectric infrared sensor is triggered and infrared image sensor nodes start immediately for capturing images. Light sensors will determine whether the light is adequate or not. If the light is adequate, color photographs will be taken. If the light is not adequate, infrared LEDs start automatically for lighting and black and white photographs will be taken. Meanwhile, GPS positioning module starts automatically for obtaining positioning data. Infrared image sensor nodes will process the data locally and transfer the processed data to the sink node. The sink node is deployed in locations with 3G networks coverage and sends data to the base station through 3G networks. Base station connected to the internet is responsible for transmitting the received data to the wildlife monitoring center over the internet. Wildlife monitoring center is equipped with 3D GIS system and a wild animal image information database. Researchers can store and analyze the collected data.

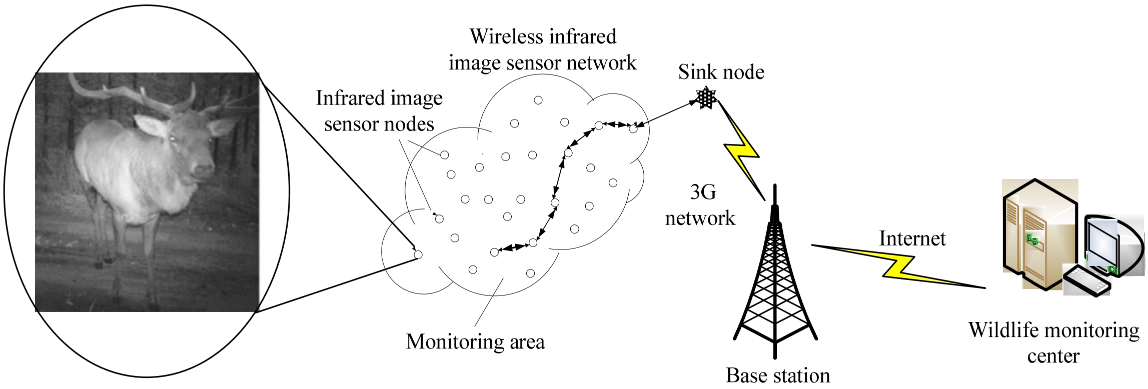

Fig. 1. The architecture of wildlife monitoring system based on wireless image sensor network.

4. Hardware Design

Nodes are the basic units of the wildlife monitoring system based on WISNs. Nodes include wireless infrared image sensor nodes and a sink node. Wireless infrared image sensor nodes are responsible for obtaining monitoring information and are the basic units of the monitoring system. The sink node is the hardware infrastructure connected to WISNs and the access network. The hardware design for these nodes is critical for functionality and performance of the entire system. Next, we present the detailed design of a wireless infrared image sensor node and a sink node.

4.1. Design of Rotatable and Self-powered Wireless Infrared Image Sensor Nodes

Wireless infrared image sensor nodes are the basic units of a WISN. To build a ZigBee protocol-based wireless infrared image sensor network system, the main task is to develop low-power wireless infrared image sensor network nodes for power efficiency.

The structure of a wireless infrared image sensor node designed in this paper is shown in Fig. 2. As can be seen in Fig. 2, the structure is equipped with three pyroelectric infrared sensors, infrared LEDs, light sensors and two servos. The sensing angle of the pyroelectric infrared sensor is 120°. Three pyroelectric infrared sensors are facing three directions, and the corresponding sensing ranges do not overlap. Infrared image sensor nodes usually lie dormant. Once a wild animal enters the detection zone, infrared image sensor nodes start immediately to capture images by controlling the rotation angles of the two servos and adjusting the camera lens to the direction faced by the pyroelectric infrared sensor detects the wildlife. Light sensors will determine the lighting condition. If the light is sufficient, color photographs will be taken, otherwise, infrared LEDs start automatically for lighting and black and white photographs will be taken. A wireless infrared image sensor node can achieve all-weather acquisition, compression and transmission of infrared image data of wildlife. It can communicate with other infrared image sensor nodes and achieve the GPS positioning function.

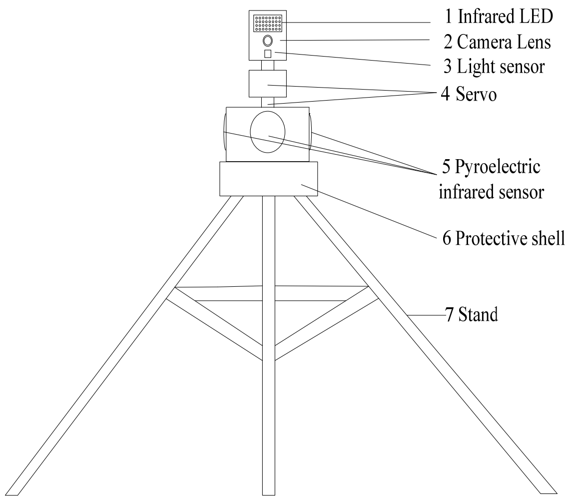

Fig. 2. The structure diagram of a wireless infrared image sensor node.

Given the characteristics of image data processing and energy consumption, wireless infrared image sensor nodes based on ARM7 are designed in this paper. A wireless infrared image sensor node includes an image acquisition module, an image processing module, a ZigBee transceiver, a GPS module, and a solar energy supply module. The specific hardware architecture is shown in Fig. 3.

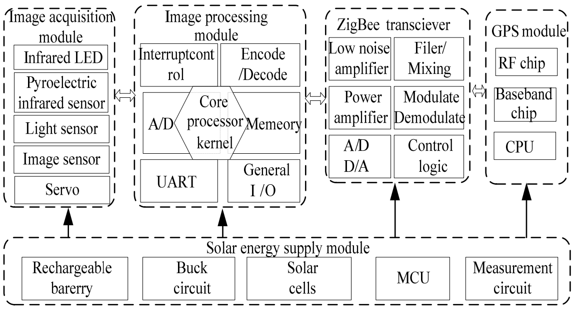

Fig. 3. Specific hardware architecture of a wireless infrared image sensor node/module block diagram.

The processor used in our sensor nodes is the Atmel AT91SAM7X512, which is based on ARM7TDMI (a 32-bit RISC architecture). It operates at a maximum speed of 55 MHz and features 512 kB of flash and 128 kB of SRAM. Typical core supply is 1.8 V. I/Os are supplied at 1.8 V or 3.3 V and are 5 V tolerant. It can set the parameters of the imager, instructs the imager to capture a frame and run local computation on the image to produce an inference. We adopt TI CC2520 as the ZigBee transceiver. The CC2520 is TI's second generation ZigBee/IEEE 802.15.4 RF transceiver for the 2.4 GHz unlicensed ISM band. This chip enables industrial grade applications by offering state-of-the-art selectivity/co-existence, excellent link budget, hardware support for frame handling and low voltage operation, thus reducing the load on the host controller. It connects to the processor through SPI. The image sensor module for our platform is OmniVision OV7670 combined with embedded DSP OV529. The OV7670 image sensor is a low voltage CMOS sensor that provides the full functionality of a single-chip VGA camera and an image processor. The OV7670 provides full-frame, sub-sampled or windowed 8-bit images in a wide range of formats, operating at up to 30 frames per second (fps). It is controlled through the serial camera control bus (SCCB) interface. The OV529 serial bridge contains an embedded JPEG CODEC and a controller chip that can compress and transfer image data from the camera sensor to an external device. The image sensor module connects to the processor through UART. HC-SR501 sensor module, as the pyroelectric infrared sensor, is cheap, high sensitivity and its detection distance is 7 meters. Its working voltage is 4.5-20 V, and the output level is 3.3 V or 0 V. In addition, a solar energy module is developed, which consists of a microcontroller MSP430, solar cells, rechargeable battery, measurement circuits, BUCK circuits, etc, to supply power to the node efficiently.

4.2. Design of the Sink Node

The sink node aims at connecting the wireless image sensor network with 3G telecommunication network. It establishes a reliable connection and two-way data transmission between a remote server or mobile users and a wireless image sensor network to meet the practical needs. The specific hardware architecture is shown in Fig. 4.

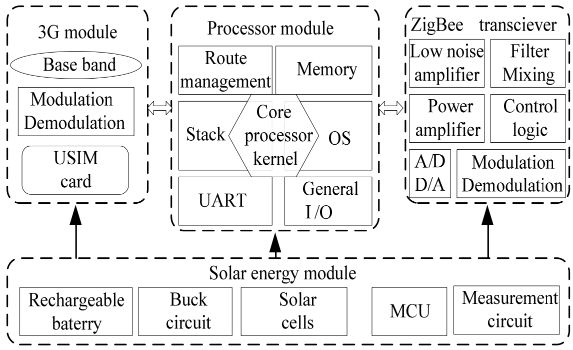

Fig. 4. Specific hardware architecture of the sink node.

The sink node consists of processor, memory, a ZigBee transceiver, a 3G communication module and other expanded interfaces. Considering the large amount of data of the sink node received, PXA270 from Marvell has been chosen as the core processor module. It incorporates the Intel XScale technology which complies with the ARM* version 5TE instruction set (excluding floating-point instructions) and works at 520 MHz. To work with the PXA270, two chips of HY57V561620 from Hynix have been selected as 64 MB SDRAM, and two chips of TE28F128J3C-150 from Intel have been selected as 64 MB Flash. CC2520 has been adopted as the aforementioned ZigBee transceiver. We choose SIMCom SIM5218 as the 3G module. The SIM5218 series is a Tri-Band/Single-Band HSPA/WCDMA and Quad-Band GSM/GPRS/EDGE module solution which supports up to 7.2 Mbps downlink speed and 5.76 Mbps uplink speed services. It connects to the processor through UART.

5. Equations Software Design

System software design mainly includes the programming of ZigBee protocol stack, 3G protocol stack, and software design of wireless infrared image sensor nodes and the sink node. Since the ZigBee technology and 3G technology are more mature, the existing protocol stack program is used by the system. The study focuses on the software design of the wireless infrared image sensor node and the sink node. Since the features and tasks of the wireless infrared image sensor node and the sink node are different, they are discussed separately.

5.1. Programming of the Wireless Infrared Image Sensor Nodes

Wireless infrared image sensor nodes formed a self-organizing network are the sink node's children and grassroots links of a WISN. Wireless infrared image sensor nodes are directly associated with capturing wildlife image and passing compression-encoded image data. The main tasks of wireless infrared image sensor nodes are node wake, wildlife image acquisition, image compression, data transmission, and returning to dormancy. The specific workflow is presented in Fig. 5.

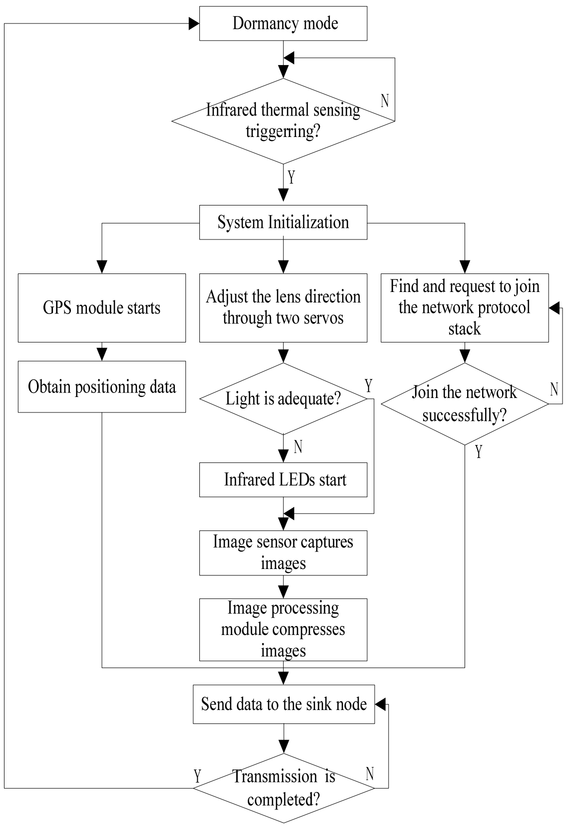

Fig. 5. Program flow chart of the wireless infrared image sensor node.

Infrared image sensor nodes usually lie dormant. Once pyroelectric infrared sensors are triggered, infrared image sensor nodes start immediately and capture images by controlling the rotation angles of the two servos and adjusting the camera lens to the direction that faced by pyroelectric infrared sensor detects the wildlife. Light sensors will determine the lighting condition. If the light is not sufficient, infrared LEDs start automatically for lighting. GPS module starts to obtain positioning data. Meanwhile, a request is sent to join the network. After the sink node responses, the infrared image sensor nodes successfully join the network and start transmitting the compressed image data and location data to the upper nodes. The upper nodes send the acknowledge bit after determining successful reception. The wireless infrared image sensor nodes return to the dormancy mode, so on ad infinitum.

5.2. Programming of the Sink Node

The sink node is responsible for building and managing a network. It allows or denies any sensor node to join the network. It collects data of the wireless infrared image sensor nodes and sends them to the base station via 3G networks. Its work process includes node wake, building network, joining node, receiving data, sending data, and returning to dormancy. The specific workflow is presented in Fig. 6.

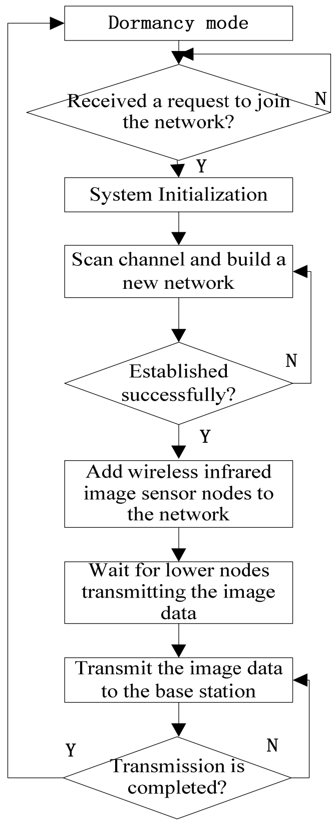

Fig. 6. Program flow chart of the sink node.

The sink node usually lies dormant. Once it receives a request signal to join the network, the system is initialized and begins to establish a network. When building the network, the sink node will continue to search for an empty channel. If a searched channel is occupied by another sink, then the search continues until an empty channel is found. When an empty channel is found, it immediately performs the appropriate identification to build its own network. According to the resource need, the sink node decides whether to allow this wireless infrared image sensor node to join. If this node is allowed to join, it is assigned a network address to build a new network. At the same time, the sink node waits for the image data and location data. Then the sink node transmits the received data to the base station via 3G networks.

6. Conclusions

Wildlife monitoring is important for effective protection, sustainable use, and scientific management of wildlife resources. Compared to the traditional wildlife monitoring methods, wildlife monitoring based on wireless image sensor networks is able to meet the new requirements, such as remote, real-time, all-weather monitoring, and capturing image information. This paper proposed a wildlife monitoring system based on the wireless image sensor networks to overcome the shortcomings of traditional monitoring methods. System architecture, design of wireless image sensor nodes and software design have been studied and presented. However, there are still many issues to be resolved in wildlife monitoring applications using wireless image sensor networks. For example, how to reduce the image compression algorithm complexity while maintaining the quality of images, how to achieve low-power local image recognition, and how to deploy image nodes to maximize the coverage of monitoring area. In our future research, we will tackle these issues.

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