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Early Detection and Monitoring of Forest Fire with a Wireless Sensor Network System

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Abstract

This work presents a low-rate wireless personal area network-based sensor network for early detection and monitoring of forest fires. The system has been designed to perform different parameter measurements at different tree heights, depending on the forest relief. Thereby, it is possible to know how fire affects the soil mantle, stems and treetops, as well as to detect underground fires. Measures of power consumption confirm the feasibility of the implementation of this sensor network. Using a duty cycle of 0.33% and with the selected low-voltage-low-power compliant sensors, the network operating life is greater than one year.

Keywords: wireless, fire prevention, sensor network, low-power

1. Introduction

Nowadays, the techniques for fire detection in large forest areas are based on satellite images and forest guard posts. However, these methods are not suitable for local measurement of the relevant parameters involved in fire risk and, hence, in its early detection. For this purpose, distributed sensing systems as wireless sensor networks (WSN) can offer a suitable measurement resolution.

A WSN consists of several sensing nodes which gather information from the surrounding environment and communicate with each other to send the measured data to a base station for further processing. The most important requirements to develop a WSN node are small form factor, to reduce the visual effect in the area where sensors are distributed, and low-power low-voltage (LPLV) operation. For this, an appropriate energy handling is essential to achieve a long battery life, requiring low power electronics for sensors, conditioning interfaces, microcontroller and transceiver. Furthermore, if the sensor network must cover large areas, distributing high amount of sensing nodes, inexpensive sensors are needed to achieve cost reduction.

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This paper presents a new low-rate wireless personal area network (LR-WPAN) system in mesh topology [1] to early detection and monitoring of forest fires. The system has been designed to perform different parameter measurements at different tree heights, depending on the relief of the forest.

This paper is organized as follows: Section 2 explains the hardware and software development of the node components and the most important ambient parameters to monitoring with their corresponding sensors. Next, in Section 3, the network topology and the communications scheme are exposed. Finally, the power consumption of prototype is analyzed.

2. WSN node development

Each mote comprises several parts:

- A microcontroller ATMega 1281, that controls and synchronizes the sensor data acquisition process, the transceiver operation and the memory access and storage.
- An XBee transceiver from MaxStream, operating in the 2.4 GHz Industrial-Scientific-Medical (ISM) free RF band. The transceiver has been programmed with the DM-24 firmware from DigiMesh.
- A set of sensors to measure the required parameters. In order to test the performance of several different types of sensor output codification, the motes include sensors with analog, digital or quasi-digital (frequency-coded) output.
- A power supply composed by two LR06 (AA) batteries, which provides the required energy for the mote components.
- A dipole antenna with an outdoor range of about 100 meters.

An important issue in the design of a sensor node is the protection against environmental conditions. Thus, the proposed motes are protected by an IP65 standard protection box.

2.1. Development tools

The design of the node sensor PCB layout was made using ALTIUM Designer. The main considerations for the node design are [2]:

- The voltage reference in ADCs must be filtered to ensure the stability in measures.
- Both bulk and decoupling capacitors were placed close to the XBee transceiver, filtering the peaks of current produced in transmission.

Mote microcontroller is programmed using the C compiler included in the Atmel AVR tools (AVR Studio 4) and the avr-libc libraries. XBee configuration is performed using the X-CTU free software from MaxStream.

The full measurement system is controlled by a computer. Control software has been developed using Matlab. This programming tool allows transferring data from the coordinator to the computer by means of interrupt-based functions using an USB-serial converter, and processing and checking the transferred data in order to provide integrated information to the end user. Moreover, a daily data backup is performed for further analysis.

2.2. Sensor Characteristics

For this work, the sensors have been selected so as to be compliant with the low-power low-voltage (LPLV) requirements. Other important characteristic is the sensor cost: in these applications, where high number of nodes will be spread in large areas, low-cost is a prerequisite.

2.2.1. Ambient parameters

Critical meteorological factors such as high temperatures, low relative humidity and lighting storms increase fire forest chances. Thus, to achieve an early detection of this risk, some important parameters to be sensed are environmental temperature, barometric pressure, light intensity (solar cycle), smoke, relative humidity, soil moisture, and temperature and humidity into the node case.

Currently we have included in the mote analog sensors to measure soil moisture (a Decagon EC-5 dielectric soil moisture probe) and light intensity (a silicon photodiode S8265 from Hamamatsu with high resistance to humidity). To monitor parameters internal to the node box, a temperature (an NTC resistor) and relative humidity (a Sencera

H25K5A resistive) analog sensors were included. Furthermore, the node includes two digital sensors, a SHT11 relative humidity sensor from Sensirion and a MS5540B barometric pressure sensor from Intersema that include compensation to temperature drifts.

Furthermore, for this application a low-power smoke sensor has been designed. This device is based on IR light refraction due to the presence of smoke into a small chamber. Chamber geometry and circuit scheme are show in Figure 1.

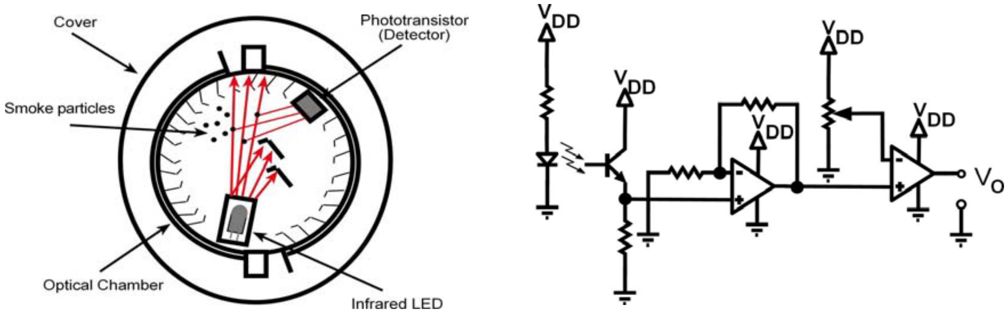

Figure 1. (a) Smoke sensor design and (b) conditioning interface

The detection process is performed directly by the appearance of smoke, allowing locating the site of fire and the fire propagation with accuracy. The rest of sensors monitor the parameters aforementioned and a message of warning appear when risk conditions are accomplished. These conditions are different in each year season and depending of geographic situation; therefore, the risk threshold must be configured by the user.

2.3. Sensor Data Acquisition

The microcontroller included in the sensor node has been programmed to control the data acquisition from the specified sensors, the signal processing, data management and communications, optimizing the mote resources to obtain an efficient implementation.

The digital sensors need a 3 or 2 wire synchronous communication protocol for their initialization, control and data collecting, that depends on the sensor specifications.

The output signal of analog sensors is converted to a binary value using the 10-bit analogue to digital converter (ADC) of the microcontroller. The binary data are converted to a value that represents the measured physical magnitude into the host PC. Quasi-digital sensors provide a frequency output signal, which can be measured using microcontroller internal timers and the Direct Counting Method (DCM) algorithm [3]. This approach offers advantages, as high noise immunity and ease of transmission.

3. WSN Topology

The communications network model is based on a Low-Rate Wireless Personal Area Network (LR-WPAN) standard architecture. The network is configured in a peer-to-peer topology (which is more powerful than a star topology for extensive surfaces), specifically in a mesh topology. This architecture makes use of sleep coordinators, that are devices which XBee transceiver has been specifically programmed to allow the synchronization of the sleep period of the rest of node devices. The introduction of these elements is essential for network maintenance.

In the development phase, the described WSN prototype collects data, which are sent to the coordinator, passing to the host PC by a serial to USB adaptor.

In the future, installing a GSM/GPRS module in the network node coordinator, data may be received by the user by means of mobile communication protocols, providing more flexibility and capabilities to the system.

4. Power Consumption

To reach a long node operating life it is needed an efficient power management of the mote. The operating life strongly depends on the time that the sensor node is transmitting and therefore on the times it is woken up.

To minimize power consumption, sensors are disconnected when the system is in sleep mode using analog switches. In addition, the microcontroller is programmed using the different available power reduction modes. Interrupts, as ADC noise reduction, timer/counter overflow and data reception, reduce the power consumption in measurement and communication periods.

Currently, all sensor nodes are supplied with two 1.5 V LR06 batteries whereas coordinator does it from USB connector. In the next phase, solar panels and rechargeable batteries will supply the coordinator energy.

Figure 2a presents the power consumption of the full mote operation, assuming 2 s of measuring period and a duty cycle of 0.33 %. Depending on the mote state, the system presents three different power consumption levels: First level corresponds to the system in sleep mode. In this case, power remains below 108.3 μW. Second level corresponds to the measurement time. In this case, microcontroller, transceiver and sensors are switch on, giving a power consumption of 165.6 mW for 280 ms. Finally, in the third power level (159.6 mW), both sensors and microcontroller are switched off, remaining on the transceiver to complete the data transmission.

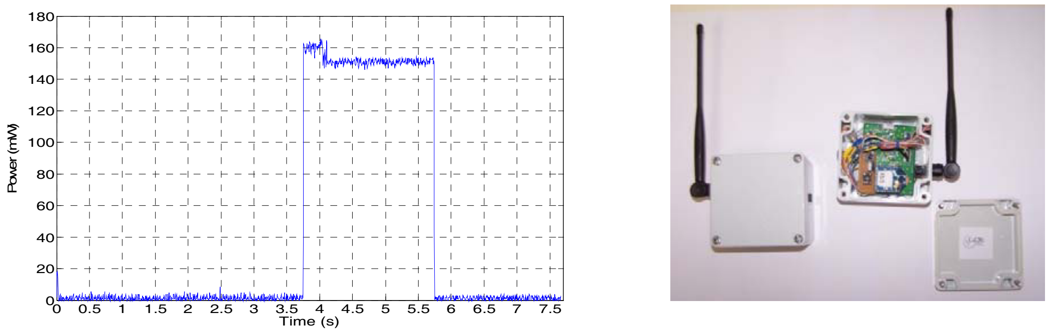

Figure 2. (a) Power consumption of (b) node designed for network

5. Conclusions

This paper presents the development of a wireless sensor network useful for monitoring large surfaces of forest to detect and prevent forest fire. Figure 2b shows a picture of the actual prototype node.

Measures obtained of power consumption confirm the viability of the implementation of this sensor network. Using the duty cycle proposed in the previous section and measuring the internal and external temperature and relative humidity, barometric pressure, light intensity, the network life time is greater than one year.

In the proposed system, both the microcontroller and Matlab software make checksum verification to ensure the accurate data reception. This could be redundant, but it is necessary for the detection of communication errors.

Due to topology and sensors are not fixed, versatility of the node design allows different applications. Some modules, as smoke sensor or GPRS/GSM connection are currently in development phase. Provisional results carry out the constraints.

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