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Wireless Sensor Network for Crop Field Monitoring

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***Abstract*—This paper presents the design and the implementation of a Wireless Sensor Network that can monitor the air temperature, humidity and ambient light intensity in a crop field. This can help the end users such as farmers in the better understanding of agriculture practices to be adopted for crop management. Since, early detection of plant fires is necessary to prevent high crop damages; a plant fire detection scheme has also been incorporated in the system. The system consists of nodes, which are equipped with small size application specific sensors and radio frequency modules. The sensor data is transmitted via radio frequency link to the centrally localized computer terminal for data logging and analysis. The design also includes an alternative scheme for the storage of sensor data into an EEPROM in case the computer terminal switches OFF like in the case of a power failure. The sensor nodes can additionally be programmed from the computer terminal itself according to the changing needs of farmers, thus preventing the need for a redeployment of the Wireless Sensor Network every time some changes are to be made. The Graphical User Interface has been made very user-friendly keeping in mind that the system will be used predominantly by the farmers. Since energy is the main operating constraint, sleep mode of the core components is utilized. The system design implemented addresses a wide range of agricultural concerns from detecting sensor node failure, retasking the sensor nodes, power management and data reliability considerations. The proposed system has been deployed in a brinjal field and the feasibility of the network is tested by evaluating the field results.**

Keywords-crop field monitoring; wireless sensor network; temperature; humidity; ambient light intensity; energy-efficiency

I. INTRODUCTION

Wireless Sensor Network (WSN) consists of spatially distributed autonomous devices which use sensors to cooperatively monitor physical or environmental parameters such as temperature, sound, vibration and pressure. WSN has emerged as a viable technology in the agricultural sector, where the sensor nodes are deployed in outdoor fields to monitor soil conditions such as moisture, air temperature and ambient light intensity. Data collected from the sensors play a key role in crop management and crop productiveness [1]-[6].

One example of how crop management can be enhanced using WSNs is the project Accenture [7] carried out in Northern California. Accenture Technology Labs installed a WSN at Pickberry Vineyard across a 30-acre area to continually sense air temperature, humidity and soil moisture. Since viticulture is highly sensitive to climatic conditions, therefore the sensor data combined with other data sources such as weather forecast data helped farmers in the better understanding of agriculture practices to be adopted for crop management. Another application of WSN in agriculture field is Greenhouse monitoring [8]-[10]. Temperature and humidity, which play a vital role in determining the quality and productivity of crops, are controlled inside the commercial greenhouses using WSNs. Sensors installed at different locations in greenhouses are used to communicate the climate parameters data to the centralized control that helps in the proper working of automation system. The WSN can detect the differences in the greenhouse climate due to the disturbances such as direct sunshine on greenhouse walls and transmit the data to trigger the automation system. The automation system by evaluating the sensor data adjusts the greenhouse interior climate to optimal climate conditions.

WSNs have also played a critical role in the detection of forest fires and plant fires [11]-[13]. Uncontrollable fires like plant fires can cause significant damage to human and natural resources. For example, in the year 2007, there were 8945 forest fires registered in Croatia out of which 61% were plant fires that caused huge destruction to human as well as animal life. Sensor nodes in a WSN can determine and transmit the location of the source of fire to fire fighting department before the fire expands to other regions and causes major damage.

The optimal plant growth depends upon the air temperature, humidity and active radiation of light, which results in maximum photosynthetic activity. Crop field monitoring using WSN thus represents a class of network applications with enormous potential benefits for the farmers and society as a whole. In this work, a Wireless Sensor Network has been implemented, that can monitor the air temperature, humidity and ambient light intensity in a crop field. Continuous monitoring of these key environmental variables can help farmers in improving the quality and productivity of crops. Since, early detection and suppression of plant fires is crucial in restricting them, a plant fire detection scheme has also been incorporated in the system. The design also includes implementation of necessary network services like power management, status monitoring of sensor nodes and remote data access.

The remainder of this paper is organized as follows. Section II presents the system architecture of the WSN describing the functionality of individual components and how they operate together. Section III presents the hardware design of sensor nodes forming the patch network in detail.

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Section IV describes the design and working of the gateway model. Section V discusses the results obtained from the initial deployment of sensor nodes in a brinjal field. Section VI provides the concluding remarks and outlines the future work.

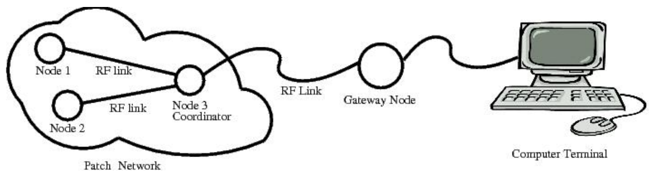

Figure 1. Topology of WSN.

II. SYSTEM ARCHITECTURE

Fig.1 shows the topology of WSN implemented in the design of the WSN. A hierarchical architecture as in [14] has been adopted. At the lowest level of hierarchy are two sensor nodes, each sensing temperature, humidity and luminosity in addition to general purpose computing and networking. The computational module on each sensor node is a programmable unit that performs computation, storage and bi-directional communication with other sensor nodes. It interfaces with the digital sensors on the sensor module and dispatches the data according to the application needs. Since the wireless communication range provided by the radio frequency (RF) modules is more than 1 km, the sensor nodes can be widely separated. Sensor node 1 and sensor node 2 transmit their data through the wireless communication link to sensor node 3, which acts as a coordinator. The coordinator aggregates the data from the two sensor nodes in a time-multiplexed manner, which helps in avoiding collisions of data transmissions. It then transmits its own sensor data along with the data collected from the other two sensor nodes to the next higher-level gateway node via a wireless link. The network formed by the three sensor nodes is called a patch network. The advantage of making a sensor node coordinator is that the total field area that can be monitored by the WSN is doubled than by sensor nodes when directly communicating with the gateway node. The gateway then transmits the sensor data received from the coordinator to the remote computer terminal through RS-232 serial interface. The computer terminal has the facility of data logging and the temperature, humidity and luminosity measurements can also be uploaded over Internet for further investigation. The Graphical User Interface (GUI) has been made very user-friendly keeping in mind that the system will be used predominantly by the farmers.

III. PATCH NETWORK

The patch network consists of three nodes where each sensor node comprises of small size sensors and general purpose computing elements. The sensor nodes can be deployed at various locations in a crop field to monitor environmental changes. The main components in the sensor node and the special features of patch network are outlined below:

A. RF Modules

The XBEE-PRO RF Modules [15] manufactured by Digi are used to provide the required wireless RF communication link amongst sensor nodes and gateway. The modules are engineered to meet IEEE 802.15.4 standards and provide reliable delivery of data between compatible devices. They operate within the ISM 2.4 GHz frequency band and provide a wireless communication range of 1500 m in open space. They require minimal power and support the unique needs of low-cost, low-power wireless sensor networks. The modules are programmed using dedicated programming kit to make them compatible for wireless communication.

B. Sensors

Low power consumption, fast response time, tiny size, long term stability and superior signal quality makes Sensirion SHT15 [16] a perfect solution for crop field environment. It is a single chip relative humidity and temperature multi sensor module comprising a calibrated digital output. Temperature and humidity accuracy of the sensor is ±0.4 °C and ±0.2 % respectively. The 2-wire interface and internal voltage regulation allows easy and fast system integration. The sensor switches into automatic sleep mode after each measurement to conserve power and has a facility of internal connection reset in case of lost connection.

TAOS TSL2561 [17] is used to measure the ambient light intensity level. It is a light-to-digital converter that transforms the light intensity into a digital signal output and uses direct I^2C interface to communicate with the microcontroller. Each device combines one broadband photodiode (visible plus infrared) and one infrared-responding photodiode on a single CMOS integrated circuit capable of providing a near-photopic response over an effective 20-bit dynamic range. This digital output is input to the microcontroller, which computes the ambient light intensity in Lux using empirical formula to approximate the human eye response.

Both the sensors do not require any external components for signal conditioning thereby saving valuable PCB area. Another key aspect for choosing these sensors is that the output from both the sensors is immune to noise and external disturbances due to its digital nature. The start up time in both the sensors is very low. Therefore current is not needed for a long time during initialization thereby reducing the power consumed. The power saved can be used to perform other computing tasks. Another advantage is that the sensors can be deployed quickly in the field since no calibration is needed prior to deployment.

C. Sensor Node

The basic model of the sensor node is depicted in Fig. 2. Each sensor node consists of SHT15 temperature humidity multi-sensor module and TSL2561 ambient light sensor, which monitor the environmental key variables in the brinjal field. Sensors are soldered to PCB equipped with necessary passive components such as resistors and capacitors. The sensor node operates as a basic measuring node with RF transceiver and Atmel ATmega8L microcontroller operating at 1MHz. The microcontroller acts as a CPU and performs all the computations and input-output operations required for the working of the sensor node. A sensor is interfaced with the microcontroller through two general-purpose input-output pins. One of the pins of microcontroller is bi-directional for exchanging data between microcontroller and sensor and the other pin is configured as an output pin to provide the clock to the sensor.

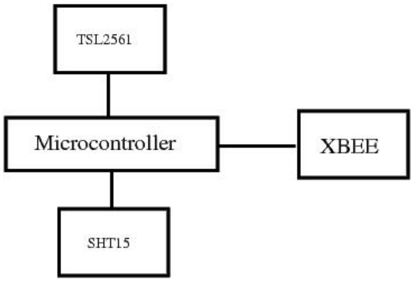

Figure 2. Basic model of sensor node.

D. Energy Considerations

Field monitoring applications require to be run for the duration of a complete field season. Therefore, the network operates under very strict energy constraints [18]-[20]. The node senses data only once in every five minutes. Power Supply to the sensor node is provided with an On-Semi NCP1421 step up dc-dc converter. It is a monolithic micro-power high frequency step up switching converter specially designed for battery operated electronic products. It boosts the 2.5 V supply voltage provided by a pair of AA NiMH rechargeable batteries connected in series to a stable voltage source of 3.3 V. The batteries are able to supply 2200 mAh at 3.3 V. One of the special features of NCP1421 is that it can detect low battery level indicating the need to charge the batteries.

The power supply unit is integrated with the sensor node board. To withstand the variable weather conditions, the entire sensor node board is mounted in an acrylic enclosure that does not affect the sensing functionality. Since, the acrylic covering is transparent to infrared and radio frequency; it does not obstruct the wireless communication.

E. Status Monitoring of Sensor Nodes

A simple strategy for detecting sensor node failure is implemented. Sensor nodes also transmit their power supply voltage level along with the sensor readings to the gateway. The voltage level readings can be used to determine when to charge the rechargeable batteries of the sensor nodes and also in detecting a node failure.

IV. GATEWAY MODEL

Gateway is used as a bridge to link the wired and wireless network. Fig. 3 explains the elementary model of the design of the gateway node. The gateway node receives the sensor data through coordinator using the RF communication link. The sensor data is transferred to the microcontroller A through UART interface. Microcontroller A performs all the processing of sensor data. The data is transmitted from microcontroller A to other microcontroller B via Two Wire Interface. The microcontroller B continuously checks for the opening/closing of the serial port. If the terminal is switched ON, the field data is displayed on the GUI and is also logged for future analysis. If the terminal is switched OFF, the sensor data is stored in the EEPROM along with the time details that can be retrieved and analyzed when the terminal is again switched ON.

A. Data Logging

The remoteness of the field sites requires the system to prevent any loss of data in case the computer terminal switches OFF due to a power failure or any other malfunction. It is also possible that the personnel are present at the computer terminal only for few hours per day. So in order is to save the sensor data when the computer terminal is not available, an EEPROM is included in the gateway model for data storage. If the serial port is closed, microcontroller B stores all the sensor data into the EEPROM along with the time and date details. When the terminal is switched ON again, the EEPROM can be read to retrieve the stored sensor data along with the time and date information. The EEPROM used is the AT24512 manufactured by Atmel. It is an electrically erasable PROM device that uses standard 2-wire interface for communications. It contains a memory array of 512 K-bits and operates for a wide voltage range of 1.8 V to 5.5 V.

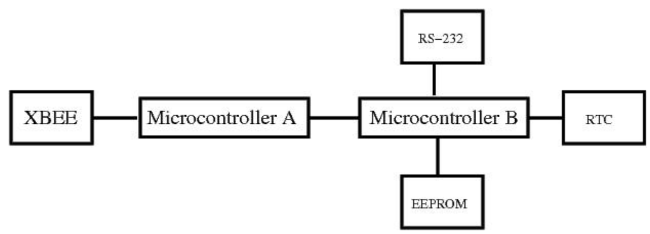

Figure 3. Basic model of gateway node.

B. Real Time Information

When the computer terminal is switched OFF, the sensor data along with the time information is logged into the EEPROM. A time stamp is required to give the actual timing details regarding the reception of sensor data when the computer terminal is not available at that time. The time information is provided by Maxim DS1302 timekeeping chip that communicates with the microcontroller via simple serial interface. It contains a real-time clock/calendar that provides seconds, minutes, hours, day, date, month and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an AM/PM indicator.

C. Power Supply

LM1117 linear regulator is used to provide a stabilized power supply of 3.3 V for the gateway board. A 12 V adaptor is used to provide the input to the linear regulator.

D. Plant Fire Detection

Gateway node receives the entire sensor data wirelessly from the coordinator. The microcontroller A analyzes the temperature and luminosity values measured by the sensor nodes. If the combined value of temperature and ambient light intensity is above a predefined threshold value, an alarm goes ON using a buzzer on the gateway board. Since each sensor node also sends its unique identifier number along with its sensor readings, the location of the fire can also be determined by analyzing the field data at computer terminal. The sampling time of sensor nodes has been kept small so that fire can be early detected and its propagation can be restricted.

E. *Offline Programming Facility*

With time, it may be required to refine the functionality of the sensor nodes. Sampling rates of the sensor nodes may be required to be adjusted according to the application needs of farmers. An offline programming facility is incorporated in the system where the microcontrollers interfaced with the sensors can be programmed without retasking the sensor nodes. The microcontrollers can be reprogrammed from the computer terminal itself through RF modules so the personnel need not go to the field to redeploy the sensor nodes.

F. *Reliablity Considerations*

In order to make sure that the entire sensor data is received by the gateway, the RF modules take care of up to three retransmissions of the data. The RF modules are in the Unicast mode [10] by default. In this mode, the receiving RF module sends an acknowledgement of the reception of the data to the transmitter module. If the transmitting module does not receive an acknowledgement, it will resend the data up to 3 times or until the acknowledgement is received.

G. *Graphical User Interface*

MATLAB is used to implement the GUI that enables the user to log the sensor data into a text file for further investigation. The GUI receives the air temperature, humidity and ambient light intensity data from gateway through serial port and displays it on the computer screen. It also retrieves the time from the operating system and displays the field data with a time stamp. GUI provides graphical icons and visual indicators that can be selected to Connect/Disconnect from the serial port, Start Log and End Log data into a file and make Settings for the connection. The file into which data is logged can be specified by the user and saved in the hard disk. The GUI has been made very user-friendly keeping in mind that the system will be used predominantly by the farmers.

V. RESULTS AND DISCUSSION

The proposed WSN system consisting of 3 sensor nodes has been deployed in a brinjal field. Each sensor node measures temperature, humidity and ambient light intensity values. Fig. 4 shows a sensor node with an acrylic enclosure deployed in the field. In order to conserve power and increase the lifetime of WSN, periodical sleep and wake up modes of the sensor nodes are applied. In turns, sensor node 1 and sensor node 2 wake up for 5 seconds and then go back to sleep and turn OFF their radio for 4 minutes 95 seconds. At a time, only one of the sensor nodes i.e. either sensor node 1 or sensor node 2 senses data and transmits its data on receiving a data request from the coordinator. The coordinator takes care of the data requests and polls data from the sensor nodes alternately. The coordinator radio remains active for 2 seconds to collect data from the two sensor nodes and to transmit the entire sensor data to the gateway. The coordinator radio then switches into sleep mode for 4 minutes 95 seconds. Power in sleep mode gets further minimized since SHT15 automatically switches into sleep mode after every temperature and humidity measurement and the optical sensor TSL2561 consumes very less power in power down mode.

Figure 4. Sensor node in brinjal field.

The lifetime of a sensor node is computed by determining the total current drawn in both active and sleep modes. It has been estimated that the energy available to each sensor node is 6.6 mAh per day. Calculations show that for this estimated energy available, the sensor nodes have sufficient power to run for 5 months. In case the computer terminal is switched OFF, EEPROM included in the design of gateway can store up to 12 days of continuous sensor data along with the time and date information.

The temperature and humidity values measured by the three wireless sensor nodes are shown in Fig. 5 and Fig. 6. It is clear from the results that the humidity decreased at the time when temperature increased verifying the inverse relationship between the two variables. The outdoor wireless communication range of a RF module is 1500 m. However, the deployment shows that with the growth of the brinjal, the radio range reduces. Hence, due to dense growth at the time of ripening, the wireless communication range reduces up to one third of its value in open space.

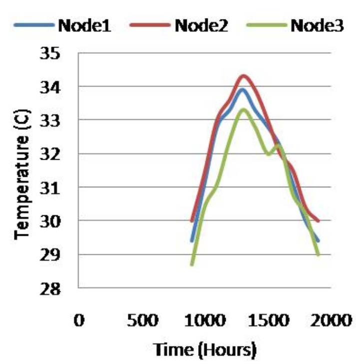

Figure 5. Temperature measurements.

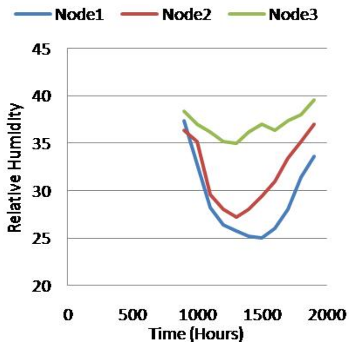

Figure 6. Relative-Humidity measurements.

VI. CONCLUSION

Crop field monitoring is an important class of sensor network applications with enormous potential benefits for the farmers and society as a whole. This paper presents the design and the implementation of a Wireless Sensor Network that monitors the air temperature, humidity and ambient light intensity in a crop field. Two commercial sensors have been successfully integrated to measure these environmental key variables in a brinjal field. The sensor data is wirelessly transmitted to a centrally located computer terminal that logs the field data within seconds. The data collected can aid the farmers in achieving maximal crop productiveness. In case the computer terminal is switched OFF, data loss is prevented by the storage of the sensor data along with the time information in non-volatile memory. Our WSN design also successfully meets the goal of detecting plant fire at an early stage. This can help in the containment of plant fire before it propagates in the entire crop field causing massive crop destruction. We have achieved a wireless communication range of more than 1 km, which can effectively monitor a normal crop field area. To make our sensor network energy efficient, sleep mode has been used for the sensors as well as the RF modules. Long network lifetime has been achieved by including a DC boost converter in the power supply design, which provides sensor nodes a stable power supply from degrading alkaline batteries. The converter can also detect low battery level indicating the need to charge the rechargeable batteries. Other special features of the design include detection of sensor node failure, data reliability considerations and offline programming facility. The WSN once installed is also economical to use since the only additional costs incurred are when the batteries need to be recharged.

In future, we plan to expand our network by adding more sensor nodes so that the coverage of an individual node decreases. This will not only reduce the time taken to detect a fire but also enhance the capability of identifying the location of the fire more accurately. Data analysis and control solutions are the other main directions of our future work.

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