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FARMNET: Agriculture Support System Using Wireless Sensor and Actuator Network

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***Abstract*—A combination of Wireless Sensor and Actuator Networks (WSAN) and information technology is emerging as a promising mechanism for cost effective real time monitoring and management solutions in variety of domains. In this paper an "Agriculture Support System" is developed using WSAN and information technology for management of large scale and commercial agriculture. It has potential of providing higher crop yields, decreasing waste and labor costs by real-time and automatic monitoring of agricultural parameters and climatic conditions. A test-bed implementation of WSAN for agriculture support system—FARMNET is created. The network senses the real time climatological and agricultural parameters influencing crop yield and relays it to the master station, a central repository. The paper describes the network architecture, hardware and software design of master station and sensor-actuator node for the real-time monitoring and management of agricultural parameters.**

***Index Terms*—Agriculture support system, wireless sensor and actuator node, hardware design, software design.**

I. Introduction

"Agriculture Support System" can be developed using information technology and wireless senor and actuator network (WSAN) for higher crop yields at a low labour cost. The system offers several advantages including faster response to confrontational climatic conditions, better quality control of the crop produce and at a lower labor cost. It requires rigorous sensing of climatic conditions and prompt communication of the sensed data to a master station (central repository). The central repository server, with its high computational power, does the decision making to control the farm irrigation and fertigation equipments. With the advances in sensing technologies, information of parameters, which may have a devastating effect on the farm yield, such as amount of rain, soil moisture, ambient light, temperature and moisture can be collected in real time. This information can be used to automate actuation of devices that control irrigation, fertigation and pest control to counterpoise the hostile conditions. A typical "Agriculture Support System" consist of: (i) hardware to sense agricultural data (ii) transferring sensed data to master station (iii) decision making at master station and (iv) actuation based on sensed data. Irrigation system based on agricultural sensors and valve-controlled actuators like sprinklers is already available in the market. However, limited work has been done in this field using WSAN. This paper presents a test-bed implementation of a WSAN for agricultural parameter monitoring and control. The rest of the paper is organized as follows. Related works are described in Section II. The proposed hardware and software of the WSAN is described in Sections III and IV, respectively. Performance of the system is reported in Section V and finally the paper is concluded in Section VI.

II. Initiatives for Agriculture Support System Using Wireless Sensor Networks

Blackmore et al., in 1994 [1] defined "Agriculture Support System" as a complete system designed to improve agricultural production by wisely adapting soil and crop controlling to match up to the distinctive state found in each field while maintaining ecological features. During the early years the sensing and communication electronic equipment for Agriculture Support System required high initial investments leading to only a few instances of their implementation. However, as the years passed a new class of networks called Wireless Sensor and Actuator Network (WSAN) that expand human ability to monitor and interact remotely with the physical world evolved. The following developments led to the expansion of WSAN:

- Moore's law offered required CPU performance in terms of power and size [2].
- Material science offered sensing materials for chemical, biological and physical sensing.
- Wireless transceivers are reduced in size, cost and power requirements [3].
- Technologies for improvements in batteries and passive power sources like solar energy are available [4].

These advances make it possible to use WSAN in a plethora of domains like Agriculture Support System, industrial automations, military, healthcare to planetary explorations. [5]. A number of sensor and actuator nodes are commercially available for these applications [6]. In Agriculture Support System, WSAN could be the backbone for monitoring environment, soil, insect, disease and weed to implementation of Greenhouse capable of adapting to different plant species in different seasons is presented in [7]. Sensor node in the system consist of Texas Instrument's low power chip MSP430F149 controller, Chipcon's CC1100 chip as transceiver with soil humidity, temperature and pH sensors. The LOFAR (Low Frequency Array) Agro Project [8] measures climatic conditions in potato farm to gather information to combat a fungal disease called Phytophtora. Sensor and actuator nodes measure temperature, soil humidity, luminosity, air pressure,

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precipitation, wind strength and direction. A decision support system then triggers actions like sprinkling varying amount of fertilizer and pesticides. "Smart Field System" project of the US Government's Agriculture Department consist of networked wireless nodes that automatically detect climatic parameters to determine the schedule of water, fertilisers and pesticides for the plants [9]. Work in [10] proposes "SoilNet", a Zigbee based mesh network that measures soil moisture for controlling the pattern of groundwater recharge. In India, Wireless Sensor Networks (WSN) to estimate crop water requirement is implemented at Sula vineyard in Nashik [11]. The nodes collect the soil water content and temperature data which are analysed to establish correlation between sensors output and agricultural requirement in terms of water management that affects growth, yield and quality of grapes. An Irrigation Management System (IMS) proposed in [12] incorporates a remote monitoring mechanism through a General Packet Radio Service (GPRS) modem to report soil temperature, soil moisture, energy consumption and received signal strength indication (RSSI) of sensor nodes at the central station. A Wireless Data logger System called "AgroSense" is developed in [13] to collect the environmental conditions like temperature, humidity, pH content of soil, moisture and humus content of the soil and relay these information in real time to a central station. This information at the central station, is used for monitoring, and real-time tracking of agriculture environment. Further, the data will be used for robotic farming to automate the entire farming process from seed sowing to harvesting. Most of the work presented above focus on sensing and does not consider feedback based control mechanism. The WSAN along with a decision making system can be used to sense essential agricultural parameters and decide about effective irrigation, fertigation and pest control schedule. The system can sense parameters like light, rain, moisture, applied water volume and injected fertilizer concentration. This paper presents the network architecture, master station and sensor-actuator node hardware design for web-based real-time monitoring and management of agricultural parameters.

III. Hardware for FARMNET

FARMNET, the proposed test-bed implementation of WSAN for agriculture support system consist of the leaf nodes for sensing moisture, rain, light, temperature, humidity, intrusions in real-time and transmitting it to the master station node for decision making and triggering the actuation. A brief description of each component is presented in the subsequent paragraphs.

A. Leaf Node

1) Moisture Sensor: It is a three pin device (V_{CC}, GND and SIG) with two probes used to measure soil moisture [14]. The two probes acts as variable resistor. When the water content in the soil is more, the conductivity of soil is more and the effective resistance is less, resulting into higher SIG output. The recorded value of the SIG is then compared with a threshold value and when this value drops below a threshold level, it is an indication that soil moisture has gone below the requirement and irrigation should be done (see Fig. 1).

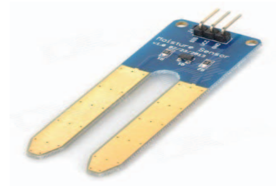

Fig. 1. Moisture sensor [14].

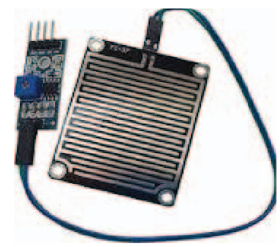

Fig. 2. Rain sensor [15].

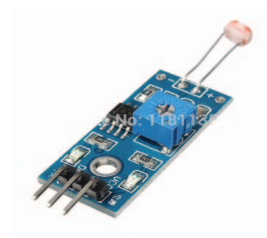

Fig. 3. Light sensor [16].

2) Rain Sensor: It is used to estimate the annual average rainfall and rainfall intensity in any time duration throughout the year. It is used for measuring the water level of the farms that is beyond the capacity of the moisture sensor [15]. A potentiometer is provided on the board for adjusting sensitivity of the sensor. It is an analog sensor with built-in resistive paths. The change in resistance is proportional to the amount of rain drops falling per unit length and this in turn varies the voltage at the output pin (see Fig. 2).

3) Light Sensor: The light sensor uses GL5528 photoresistor to detect the light intensity of the given environment [16]. It is calibrated using the divider circuit followed by a LM358 Op-Amp configured as "voltage follower". The use of Op-Amp increases the reliability and accuracy of the device. The sensor is used for checking the weather condition such as cloudy or clear sky and daily hours of sunlight (see Fig. 3).

4) Temperature Sensor: The DHT11 temperature sensor is used for measuring the environmental temperature and humidity of the area where the farm is located [17]. Analysis of these values can be used for deciding the type of crop that can be grown in the given area. It is a digital sensor that offers highest reliability and accuracy with least cost and a low voltage requirement of 3–5 V which is easily available (see Fig. 4).

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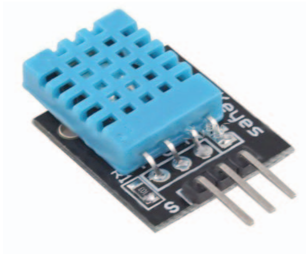

Fig. 4. Temperature and humidity senor [17].

Fig. 5. PIR sensor [18].

5) PIR Sensor: An array of PIR sensors is installed in the farm to cover all the direction for intrusion detections in the farm [18]. This method is less costly compared to installing cameras with server setup at the farm. On detecting the presence of animals and birds, sirens are blown to get rid of the birds and unwanted animals from the farm. This is more effective compared to the traditional methods used by farmers such as putting up a scarecrow. The array of five sensors is used to get a conical coverage of up to 20 feet. The sensors work in infrared range and are programmed to notify the presense of animals, birds and intruders (see Fig. 5).

6) Collection of Data and its Interpretation: The data from all the above listed sensors is collected by Arduino UNO [19] consisting of an ATMega328P microcontroller working at 16 MHz. Arduino UNO has 14 digital input/output pins and 6 analog input pins for interfacing the sensors. It has an USB connector with In-Circuit Serial Programming support. It also supports various communication protocols such as SPI, I2C and UART.

7) Transmission of Data to Master Station: For transmitting collected sensor data over the Internet, various technologies such as Wi-Fi, WCDM, GPRS can be used. Since sensor data doesnot have multimedia information, GPRS is used to transfer it over the Internet. The sensor data is sent via GPRS technology using AT commands which are programmed to execute sequentially using ARDUINO. The GSM module is interfaced with Arduino for real-time transmission of data from sensor nodes to the farmer's mobile [20].

B. Master Station

Master Station is designed using Raspberry Pi (RPi) B+ which is configured to run as a server [21]. The B+ Model is built on Broadcom BCM2835 SoC with 512 MB SDRAM, 40 GPIO pins, SD storage facility, 3.5 mm audio jack, HDMI support, 10/100 BaseT Ethernet socket and 4 numbers of USB 2.0 connector. These features make it the best candidate for running a server. The sensor data sent by leaf nodes using GPRS service is relayed through the DNS and collected at RPi which is connected to the Internet (see Fig. 6).

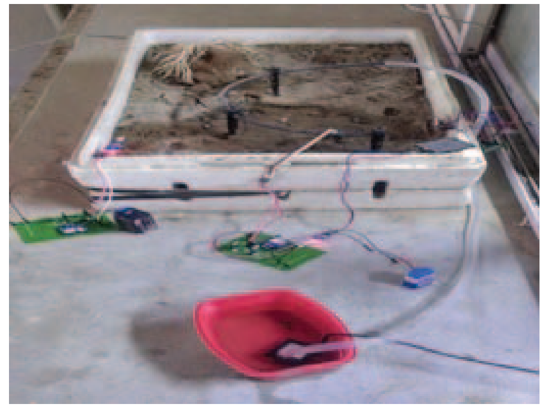

Fig. 6. FARMNET laboratory setup.

IV. Software for FARMNET

A. Operating System for Master Station

Raspbian, a free Operating System (OS) based on Debian and optimized for the RPi hardware is used as OS for Master Station [22]. It consist of the set of basic programs and utilities to run the RPi along with 35,000 packages, pre-compiled software bundled for utilities like editor, compilers for scripting languages, video players and word processors [23]. Raspbian is based on ARM hard-float (armhf)-Debian 7 "Wheezy" architecture port with LXDE desktop environment optimized for the ARMv6 instruction set of the RPi.

B. Programming of Master Station

1) Python: A web application using python with 'Flask' framework is created to collect sensor data sent to RPi through Internet [24], [25]. The web application consist of a structured URL to collect and store data sent to the server. The application runs on RPi over a user specified port (different from port where http runs) and listens for data coming from Internet via the specified port.

2) PHP: PHP is a server scripting language for making dynamic and interactive web pages. PHP code is interpreted by a web server with a PHP processor module, which generates the resulting web page. PHP commands can be embedded directly into an HTML source document rather than calling an external file to process data. It has command-line interface capability and can be used in standalone graphical applications. The sensor data on the server is dynamically updated on the server using PHP.

3) Apache: The sensor data collected at RPi is floated on the Internet through a website portal using a web server. This is done using Apache, the open source server. PHP coding is done to facilitate dynamic updates recorded in the database

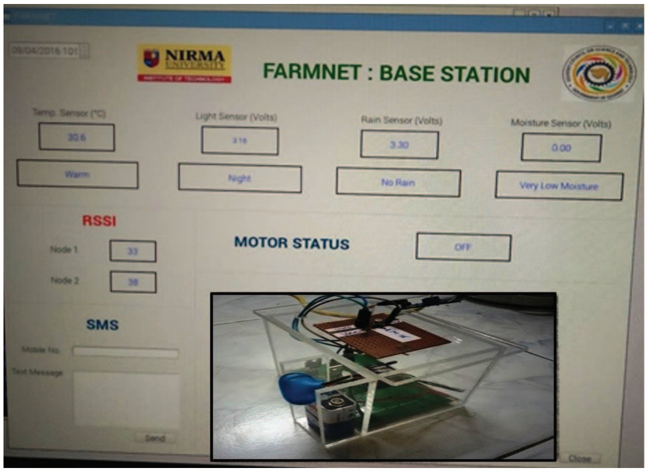

Fig. 7. Real time sensor data, RSSI collected from leaf node along with motor status and camera feed.

being updated simultaneously on the website deployed with Apache. The site can be accessed from the Internet through 'farmnetwork.in' domain name. As shown in the Fig. 7, the webpage hosted at 'farmnetwork.in' displays the real time sensor data and signal strength (RSSI) of the leaf nodes. It also displays the camera feed and motor status. It also has the facility to enter the mobile number for sending SMS when the motor is turned on.

C. Programming of Leaf Nodes

Round-robin software architecture [26] is used to program leaf nodes because: (i) there are limited number of input (sensors) output (actuators), (ii) there is no lengthy processing code and (iii) there are no tight response requirements in the node. The program collects the data from the first sensor and starts the GPRS service to transmit the sensor data. The data is received at the master station (RPi), processed by Flask server framework and displayed on the screen. The server connection is then closed. After a delay of 5000 ms, the program code is repeated to receive the data from another sensors in a fixed order. After the data is received from one sensor, same cycle is repeated for remaining sensors in the respective order with a fixed delay of 5000 ms between each sensor data collection cycle. This prevents one function collecting data from sensors to completely take charge of the program control, giving a fair chance to all the functions to execute and collect data from all the sensors.

D. Configuring GSM using AT commands

AT commands are used to send and receive data through the GSM modem [27], [28]. GPRS service is used to send sensor data from leaf node to the master station.

E. Camera for Disease and Intrusion Detection

For disease and weed monitoring camera is kept in the field and its live feed is transmitted to the master station through the Internet. For the live feed on the RPi the motion package

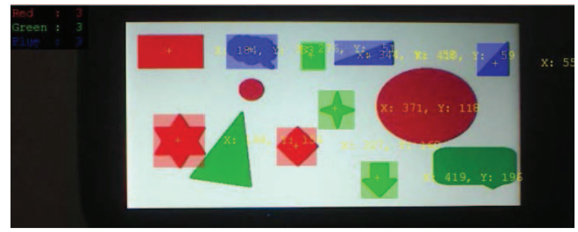

Fig. 8. RGB detection in Matlab.

is used and the motion.config file is modified to: (i) turn on the real time streaming service, (ii) set the desired frame rate, (iii) set desired height and width of video feed [29]. The motion daemon is used to start the live feed.

F. Detectiion of Soil Content

The Rapitest soil test kit is used to detect the Nitrogen, Phosphorous, Potassium content and the pH value of the soil [30]. The original system uses "Color Comparators"—with a color chart and color-coded capsules for each ingredient test. For testing of soil ingredients, the soil is mixed with water and the color-coded capsule. The soil ingredient are identified by comparing color of the solution with color chart. To automate the Rapitest Soil test kit, we have developed a code in MATLAB for color detection to identify the level of contents of soil ingredients. The MATLAB code takes the picture of the soil as input and detects RGB colors in real time to identify the hue of the soil solution and based on it the level of soil ingredients viz. whether they are depleted, deficient, adequate, sufficient or surplus. Fig. 8 shows the GUI of MATLAB code for detecting the soil ingredients.

G. Actuation

When the moisture goes below a threshold level the motor connected to the leaf node is turned on to supply water to the crops. Multiple Linear Regression [31] is applied to determine the time for which the motor should be on. The statistical model uses temperature, humidity and moisture data sent by the leaf node as a training set to predict the future timings and duration for turning the motor on.

V. Performance of FARMNET

The FARMNET was made to run in the Nirma University campus, Ahmedabad, India in the month of December. The WSAN ran successfully without any disruption. The sensor data was collected for further processing and analyzing. The ambient temperature, humidity and light were measured on every fourth day staring from 1st day in the month of December and the results are plotted in the Figs. 9, 10 and 11.

As can be seen from Fig. 9, the daily maximum temperature falls from 31 °C to 27 °C as the month progresses. As seen in the Fig. 10, the ambient relative humidity typically varies from 27% (dry) to 84% (humid) over the course of December in Ahmedabad, rarely dropping below 17% (dry) and reaching as high as 100% (very humid). Over the progression of December, the length of the day in effectively constant in

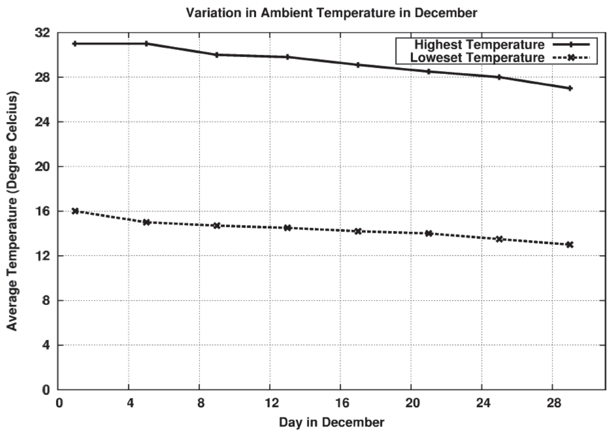

Fig. 9. Variation of ambient temperature.

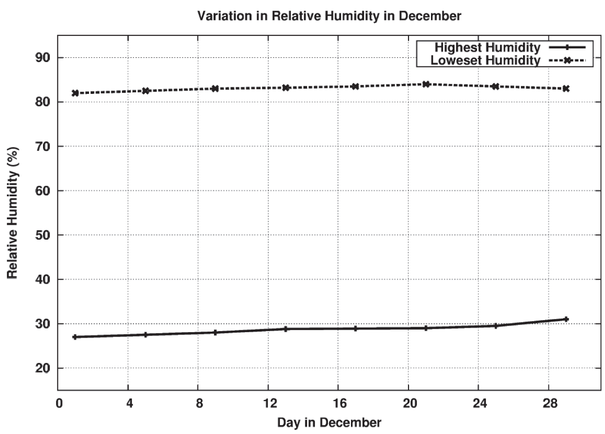

Fig. 10. Variation of ambient humidity.

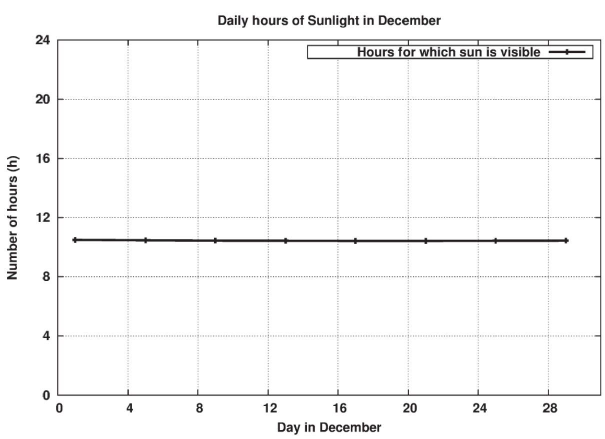

Fig. 11. Variation of ambient light.

Ahmedabad. The shortest day of the month (number of hours for which the sunlight is seen) was observed on December 19 with sunlight visible for 10 h 43 min as depicted in the Fig. 11. The longest day was seen on December 1 with sunlight seen for 10 h 50 min. The Arduino is powered through 5 V pin. With the sensors and GSM modem the average current drawn is 80 mA during the period while the Arduino is powered up [32], [33]. So, power consumption during the power on time is 0.08 A $\times$ 5 V = 0.40 W. But, the circuitry is only powered up for 1 s out of the 10 minute repeat interval, so the average power drawn is 1 s/600 s $\times$ 0.40 W = 0.000666 W or 0.666 mW. The power supply produces the 5 V necessary for the Arduino board with 85% efficient boost switching power converter. So, 0.666 mW average power consumption of Arduino takes 0.666 mW/0.85 = 0.783 mW from the battery on an average. Adding the power consumption of 11 μW of the power supply circuit, the total power requirement is 0.794 mW. The battery pack has 3 $\times$ AA Alkaline battery with 7.5 W-hours of energy. With this, the lifetime of the leaf node will be 7500 mW-hrs/0.794 mW = 9,445 h, which is approximately 13 months duration.

VI. Conclusion

A WSAN for Agriculture Support System has been developed and tested to be operational in real world. The real world experimental observations reveal that wireless transmission range varies with humidity and environment condition. This leads to requirements of design of intermediate routing nodes in a network. The leaf nodes and the routing nodes should be designed to withstand weather changes like rain, storm, snow etc. In the future, agriculture support system will be updated with routing nodes. The system will also be upgraded with robotic farming to support various farming activities from seed sowing to crop harvesting.

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