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RESOURCEFUL SELECTION-BASED DESIGN OF WIRELESS UNITS FOR GRANARY MONITORING SYSTEMS

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ABSTRACT

The effectiveness of any granary system is grossly dependent upon the efficiency of its monitoring and control measures. The granary monitoring systems presently in use in most developing countries are based on wired networks with inevitable disadvantages that include high installation and maintenance costs. Most wireless granary monitoring systems previously developed were achieved without resort to resourcefulness of the composite units of the system. However, record information on the selection of best comparative components for wireless granary monitoring systems is not readily available. This paper designed a wireless sensor integrated system from comparison and selection of resourceful component units for monitoring temperature, humidity and light variations in stored bulk grains. The resulting composite units of the developed system were products of the best parameters trade-off in the selection of components and protocols. The sensing unit consists of the selected Grove-DHT22 Temperature/Humidity sensor with calibrated, linearized and stable digital signals output via 1-wire bus and a cheap low-power Grove-GL5528 light sensor. The resulting network had no hierarchy or parent-child relationship constraint. The low-power sleep configuration possibility of the sensor node was cyclic and synchronized.

Keywords: wireless, granary, monitoring, node, trade-off, composite.

INTRODUCTION

Grains storage condition monitoring has become imperative owing to its vital economic importance. In preventing the spoilage of stored agricultural grains, various environmental factors that include temperature, light and moisture content should be well measured and kept within a particular level. To ensure good economic and market return for grains, safe storage must be ensured through effective monitoring to avoid spoilage. Proper storage management and good quality grain are required to ensure high marketability and economic returns on grains [7]. It is therefore vital to correctly measure and controls the environmental conditions for ascertaining the quality of the grains, maintain competitive advantage in the food processing industry, and ensure food security [6, 9].

Most storage facilities for bulk grains in developing countries are inefficiently monitored with the use of wired-probes. Other wireless networks systems were also developed with various attendant drawbacks.[4] Developed Wireless CC2430 and SHT11 based Zigbee system with limited application-level based and high node failure rate. [13] Developed a SY-HS-220/Ethernet based model system with localized measurement approach and cost ineffectiveness, while [9] developed a wireless measuring system for moisture content in bulk grains stored in a silo with average accuracy and high node failure. [5, 12]developed a granary environmental monitoring and control system based on ARM9 and ARM 11 embedded monitoring systems respectively with rigorous design and imposition of high algorithm overhead in the network. However, record information is not readily available on how to effectively select resourceful wireless devices for the monitoring systems of stored bulk grains.

The considerations in the design of wireless sensors include: attainment of minimal measuring uncertainty, measurements are to be performed with minimal impact on the processes involved; measuring values are to be available in real time, sensors should function without maintenance, re-calibration, or adjustment, sensors should work with minimal interference and a minimum of care, sensor and sensor-system costs should be as low as possible, sensors are to be equipped with integrated "on-board" diagnostics. Radio communication is often the most power intensive operation in a WSN device, and hence the radio must incorporate energy-efficient sleep and wake-up modes [14, 15]. Meanwhile, design factors include operating environment and hardware constraints such as transmission media, radio-frequency integrated circuits, power constraints, communications network interfaces; and network architecture and protocols, including network topology and fault tolerance, scalability, self-organization, and mobility [2, 3, 10]. Also, power management and power conservation are critical functions for sensor networks, and one needs to design power-aware protocols and algorithms. Power consumption can therefore be allocated to three functional domains: sensing, communication, and data processing, each of which requires optimization [1, 11]. [8] Highlighted the various technologies and other protocols implemented in WSNs, and explained capabilities and operational aspects of XBee ZigBee modules. The author also presented the comparison of power consumption of different XBee ZigBee modules at different transmit power levels and in different operational mode.

The main goal of this paper is to design of a system consisting of network of wireless sensor nodes with well selected components and resourceful capabilities, for monitoring the environmental factors that may influence the quality of bulk stored grains.

METHODOLOGY

The composite units of the system were designed for best performances by comparing various categories of relevant components, and selecting the finest with optimal trade-off within varying considered characteristics. The system integrates an access node which is the coordinator with more than one end nodes. The block diagram of the end node and access node are as shown in Figure-1.

a. Sensors

The key parameters being monitored in the stored grains were temperature, humidity and light. The external sensors gave signal response to the physical quantities being monitored. The details of some sensors and the corresponding characteristics that were considered for comparison are as shown in Tables (1-3).

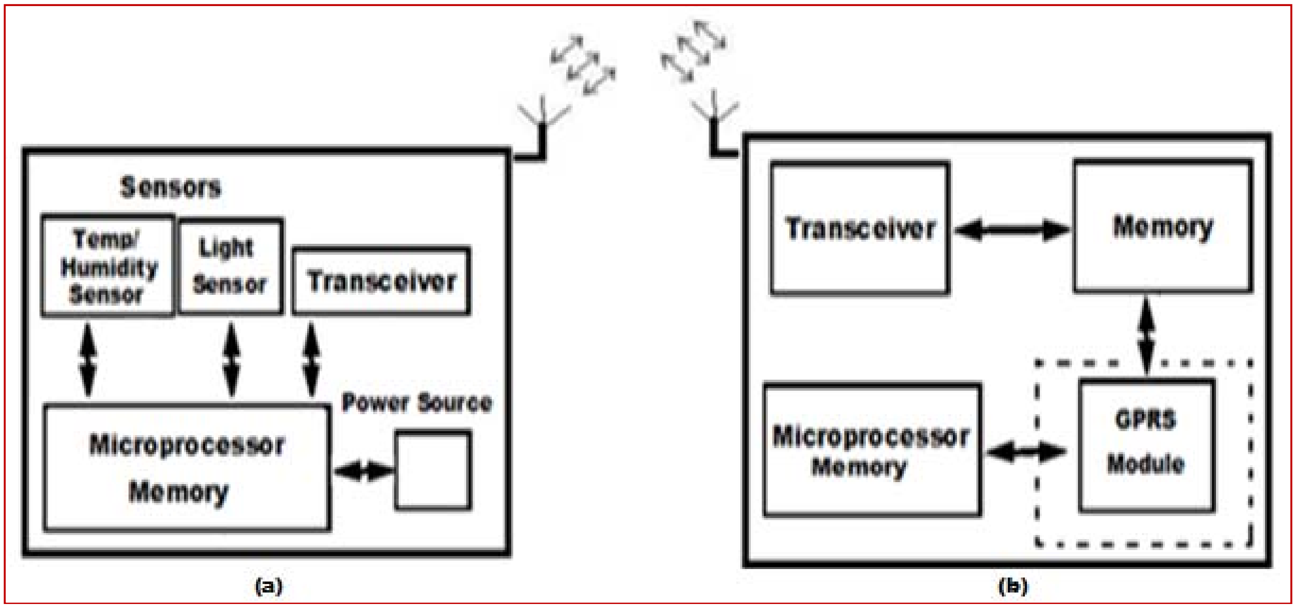

Figure-1. Block diagram of internal units of: (a) End node, and (b) Access node (Coordinator).

Table-1. Characteristics of some temperature sensors.

Features	LM Series	TMP Series	SHT Series	DHT11	DHT22
Operating DC Voltage	4 .0– 30.0	2.7 -5.5	2.1 – 3.6	2.5 – 5.0	2.5 – 5.0
Range (°C)	−55 to +150	-40 to +125	-40 to +125	0 - 50	-40 to +125
Active Current draw	60 µA	50 µA	3.5mA	2.1mA	1.1mA
Cost	$1.80	$2.00	$10.50	$5.90	$14.90
Sensing Element	Platinum film	Platinum film	Band gap Si	Thermistor	Thermistor
Size & Application suitability	Small but feeble 3 pins	Small but feeble 3 pins	Tiny & soft soldering	Small &groved	Small &groved
Long term stability	Low	Fair	Normal	Normal	Normal
Accuracy	0.5°C	2.0°C	0.3°C	2.0 °C	0.3°C
Self-heating/Heat sink req.	Yes	Yes	No	No	No
Response time/ final value	50ms/ 345s	50ms/400s	5 - 30s	3 – 10s	5 - 12s
Output Signal	Analog	Analog	2-wire/ I^2C	1-wire bus	1-wire bus

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Table-2. Characteristics of some humidity sensors.

Features	HR202 Series	SENS-HYD2	SHT1x, 2x, 7x	DHT11	DHT22
Operating Voltage (Volts)	3.3 -5.0	4.8 – 5.2	2.1 – 3.6	2.5 -5.0	2.5 -5.0
Range of measure (%RH)	0 - 60	25 - 100	0 to 100	20 - 80	0 - 100
Cost	\$4.20	\$11.25	\$10.50	\$5.90	\$14.90
Size & Application suitability	Small with PC board	Small	Tiny & soft soldering	Small &groved	Small &groved
Accuracy (%)	5	5	2	5	5
Sensed parameter	Resistance	Resistance	Capacitance	Capacitance	Capacitance
Sampling rate	Once/s (1Hz)	Once/s (1Hz)	Once/2s (0.5Hz)	Once/s (1Hz)	Once/2s (0.5Hz)
Response time / Time to final value	20 – 40s	15 – 30s	5 – 8ms	3 – 8ms	5 – 12ms
Communication/ Protocol	2-wire Analog or Digital	1-wire Analog	2-wire/ I^2C	1-wire single bus	1-wire single bus

Table-3. Characteristics of some light sensors.

Features	TSL255x Series	TSL256x Series	GL55xx Series	EE-SH3x Series	TEMD10xx Series
Operating Voltage (Volts)	2.4 -3.6	2.4 -3.6	2.4 – 5.0	1.2 - 1.5	1.5 – 3.0
Range (Lux)	0.1 - 10000	0.1 - 40000	0.1 - 600	0.1 - 25000	0.1 - 10000
Cost	\$5.00	\$5.95	\$2.90	\$4.95	\$1.50
Component	Photodiode	Photodiode	Photoresistor	Phototransistor	Photodiode
Temperature Range (°C)	0 - 70	-30 to 80	-40 to +85	-25 to +85	-40 to +85
Active Current draw	0.6mA	0.5mA	0.25mA	30mA	0.8mA
Package/Mount Type	SOIC	SOIC	Groved	PCB mount	SMIC

b. Microcontroller

The *microcontroller* was the microcomputer containing a microprocessor core, memory, and programmable input/output peripherals, designed to govern the operation of the other hardware units within the system through a set of instruction codes. Arduino board was compared with other microcontroller platforms like 8051 and PIC.

c. Nodes power unit

The sensor nodes were independent devices. Their energy and other resources were limited by size and cost constraints. The peculiarity in the deployment of wireless sensor network made the power source option limited to either battery or energy harvesting.

d. Transceivers

The transmitting and receiving of data among the nodes and within the network were the functions of the selected transceiver modules. The selection of the unit was primarily influenced by the connectivity standard and topology which were considered most suitable. Three wireless network/nodes connectivity standards were considered and compared, namely ZigBee, Bluetooth and Wifi. The details of the comparison features for these standards are as shown in Table-4. Also, the various node interconnectivity topologies and features of the selected ZigBee standard were compared with the modified Digimesh protocol which was being considered. The nodes topologies and the comparison of the features of the two protocols is as shown in Table-5.

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Table-4. Comparison of wireless network/node connectivity standards.

Features	ZIGBEE	BLUETOOTH	WIFI
Standard	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.11
Organization	ZigBee Alliance	Bluetooth SIG	WIFI Alliance
Topology	Mesh, Star, Tree	Star	Star
RF Frequency (Bandwidth)	868/915 MHz, 2.4GHz	2.4GHz	2.4GHz, 5.8 GHz
Data rate	250kb/s	723kb/s	11 to 105Mb/s
Range	10 – 300 m	10 m	10 -100 m
Power	Very low	Low	High
Battery Life	Months to Years	Days to Weeks	Hours
Network Capacity (Nodes)	65,000 (Approx)	8	32
Self healing possibility	Yes	No	Yes
Attributes/ Advantages	Reliability, low power, low cost, scalability,	Low cost, convenience	Speed, Flexibility

Table-5. Comparison of zigbee and modified digimesh protocol.

Features	ZIGBEE	Modified digimesh
Topology	Mesh / Star /Tree	Combines attributes of Mesh &Tree
Node Types	Contains full function devices (FFD) & reduced function devices (RFD)	One homogenous type. More flexibility to expand network
Battery	Only end devices can sleep	All nodes can sleep, no single point of failure
Code size	Larger. Less room for growth in features	Smaller (about half for ZigBee PRO)
Frequencies and RF Data Rates	Predominantly 2.4 GHz (250 kbps). 900 MHz (40 Kbps) and 868 MHz (20 Kbps) not widely available.	900 MHz (10, 125, 150 Kbps). 2.4 GHz (250 Kbps)
Interoperability	Potential for interoperability between vendors.	Proprietary
Addressing	Two layers. MAC address (64 bit) and Network address (16 bit).	MAC address (64 bit) only.
Maintenance	More sniffers and diagnostic tools available on market	Simpler addressing helps in diagnosing problems and setting up a network

e. Mobile alert module

Global system for mobile communication (GSM) network was selected for data communication to mobile device whenever the set threshold for the monitored parameters was exceeded. In order to select the most appropriate module unit, three mobile connectivity technologies were compared as shown in Table-6. The technologies considered were General Packet for Radio Services (GPRS), Enhanced Data rates for GSM Evolution (EDGE) and High Speed Packet Access (HSPA).

RESULT AND DISCUSSIONS

The wireless sensor system resulted from various hardware and software units being integrated together. The pictorial views of the composite nodes within the monitoring system are as shown in Figure-2. The components of the sensor node included Grove - DHT22 Temperature/Humidity Sensor, Grove - LDR GL5528 light sensor, XBee DigiMesh RF module with PCB antenna, Grove - XBee carrier, Arduino Pro mini microcontroller platform, and 9 Volts alkaline battery. The components of the coordinator included XBee DigiMesh RF module with PCB antenna, Seeeduino microcontroller platform, XBee Shield, and GPRS shield.

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Table-6. Comparison of mobile connectivity technologies.

	GPRS/GSM	EDGE	HSPA
Name	General Packet Radio Service	Enhanced Data rates for GSM Evolution	High-Speed Packet Access
Data service generation	2G & 3G	3G	3G & 4G
Data rate (Kbps)	35 – 171	120 - 384	384 Kbps – 2Mbps
Data transfer	Slow-speed	Faster than GPRS	Increasing faster
Features	Battery-friendly, SMS, more reliability	Mails and webpage, not always available	Speed, drain battery more

(a) (b)

Figure-2. Pictorial view of resulting nodes (a) End node, (b) Access node.

The DHT22 sensor was selected with a trade-off of relatively higher cost and moderately slow response in comparison to other temperature and humidity sensors. The LDR GL5528 sensor was selected with a trade-off of lesser range of measurement, which was still suitable for the system. The transceiver in the node was XBee DigiMesh RF modules. It was engineered to support the unique needs of low-cost, low-power wireless sensor networks. The modules provided reliable delivery of data between remote devices and operated within the unlicensed industrial, scientific and medical (ISM) 2.4 GHz frequency band. The module supported the ZigBee connectivity and Digimesh protocol.

Arduino board was selected due to its robust advantages over other microcontroller platforms. The Arduino is a platform based on the Atmel automatic voltage regulator (AVR) microcontroller with lots of integrated peripherals, supports high-level languages, runs with minimal support circuitry, and has a huge ecosystem (hardware, software, tutorialsIt also saved the trouble of costly printed circuit board (PCB) or bread-boarding due to its already set-up board. There were different types of Arduino boards with varying sizes, features, cost and applicability. Arduino Pro Mini was selected for the end nodes due to its advantage of a very low coat compared to Uno and other types, containing 3.3V regulator and over current protected, while Seeeduino/Arduino Uno was selected for the access node due to its pin compatibility with the GPRS shield and XBee shield.Each sensor node was powered with 9 volts alkaline battery while the coordinator and the attached peripherals were main-powered from the personal computer.

GPRS connectivity was selected with the module shield. The module was connected with the coordinator, and programmed to send alert in short message service (SMS) format to the administrator's mobile phone whenever the threshold set for the parameters of the stored grains was exceeded. The GPRS shield is compatible with all boards which have same form factor (and pin-out) as a standard Arduino Board. The GPRS shield was configured and controlled via its UART, using simple AT commands. Also, the application area of the designed system suggested the feasibility of selecting the use of battery with adequate power consumption optimization.

CONCLUSIONS

A system of wireless sensor nodes in the monitoring of environmental factors affecting stored bulk grains has been developed. The system comprised of an access node being integrated with end nodes, with self-sustaining and self-healing capabilities for autonomy and ubiquity. The energy availability to the nodes was constrained, but can be optimized for resourcefulness. This paper has contributed to the provision of information on the selection of comparatively resourceful components for wireless granary monitoring systems. It analyzed various components, topologies and technologies based some selected criteria to select the ones with comparative advantages.

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