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WIRELESS SENSOR NETWORK FOR SITE SPECIFIC CROP MANAGEMENT FOR PRECISION AGRICULTURE

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Abstract

Recently, due to significant research and development efforts, an innovative field of Wireless Sensor Network (WSN) technologies is evolving as powerful platform for systematically distributed data accumulation and data management. Because of wide application potential WSN is becoming more and more ubiquitous. It ensures the deployment of the technologies such as an embedded technology, wireless communication technology and computer information management technology etc. Emphasizing the themes of Site Specific Crop Management (SSCM), the prime objective of Precision Agriculture, the Wireless Sensor Network is designed and implemented to monitor the environmental parameters of the high-tech polyhouse. The WSN is designed for monitoring of the relative humidity, temperature and intensity of light within the poly house, in the real units. The WSN under investigation comprises ten WSNodes, routed through star networking protocol. The WSNodes are the intelligent devices, wherein the embedded technology is realized. The Hardware is designed about AVR microcontroller, wherein the standards laid down by the IEEE 802.15.4 are emphasized. To ensure wireless networking, the Zigbee devices have been employed, which are configured by the methods suggested by the Digi Corporation. The Base Station, an inherent part the WSN, is also developed and made smarter by developing the Graphical Users Interface (GUI) is dedicatedly developed in the VB environment. Therefore, to realize the monitoring of the domain-wise data of spatio-temporal variance, the WSN is established in polyhouse of smart infrastructure. The results of implementation reveal the facets of Precision Agriculture. On comparison with the standard WSN from Hanback Electronics, it found that, the WSN under investigation exhibit good reliability and preciseness.

Keywords:

WSN, Precision Agriculture, SSCM, Embedded Technology, Wireless Communication

1. INTRODUCTION

Recently, it is realized that the investigation and deployment of innovative technologies such as embedded technology, wireless communication, VLSI design and technology, mechatronics, sensor technologies etc playing vital role in the field of electronic instrumentation. During early days, wireless communication is one of the novel fields of electronics. The wireless communication emerges with innovative field called Wireless Sensor Network (WSN). This field of Wireless Sensor Network exhibits wide spectrum of applications, covering the areas such as precision agriculture, environmental monitoring and control, military and defense, medical etc [1, 2]. Therefore, due to its national as well as international relevance, many researchers are undertaking research work in the areas of Wireless Sensor Network (WSN). Particularly, for developing countries like India, where agriculture is the backbone of Indian economy, the deployment of prominent featured WSN to monitor environmental parameters for Precision Agriculture (PA) is the novel field of research.

Now days, for Precision Agriculture (PA) a new trend of greenhouse or polyhouse is emerging, Precision Agriculture is a Site Specifics Crop Management System (SSCM), based on modern techniques of Electronics and Information Technology, to monitor and control the energy intensive inputs of the crops, at right time, right quantity and at right place, to achieve optimum profitability, sustainability in the farming [3, 4, 5]. By providing controlled climatic conditions, one can significantly improve the crop yield. On survey, it is found that, the precision agriculturists are demanding highly precise system, which could ensure the monitoring and controlling of greenhouse parameters. However, if the polyhouse is having wide area and therefore, the environmental parameters are different at different locations. Therefore, agriculturist could not apply any common technique of management to the entire farm. Entire area of polyhouse could be fragmented into domains of typical areas. These environmental parameters exhibit variation from domain to domain. To monitor such environmental parameters, the centralized system exhibits more constraints. Therefore, a distributed system, Wireless Sensor Network (WSN), could be more suitable to satisfy the needs.

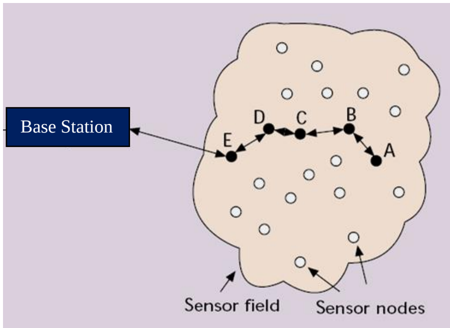

Fig.1. General Architecture of Wireless Sensor Network

Wireless Sensor Network (WSN) is the distributed network of large number of wirelessly connected autonomous devices, called Wireless Sensor Nodes (WSNode), which collaboratively collects the information about physical world and disseminates the same towards the monitoring stations called Base Station (BS) for the deterministic analysis and presentation [6]-[9]. General architecture of Wireless Sensor Network is depicted in Fig.1. The WSN is an infrastructure comprised of sensing, computing and communication elements that gives, to the administrator, the ability to instrument, observe and reset to the event and phenomena in the specified environment [10] and to ensure crop management in spatial and temporal domain. Wireless Sensor Network technology uses different protocol standards for short range wireless communication like Bluetooth [11], Zigbee [12] and Wi-Fi [13]. Out of all wireless communication standards, the Zigbee technology is most reliable and suitable for indoor as well as outdoor sensor network. Zigbee technology pioneered by Motorola and is supported by IEEE 802.15.4 standard for low data rate communication. In short, the accuracy and reliability of Wireless Sensor Network (WSN) depends on the smartness of wireless sensor node (WSNode). In order to achieve significant improvement in the performance of Wireless Sensor Network, the wireless sensor node should have good preciseness. Particularly, an embedded system based on microcontroller is found most suitable for this application. Currently, microcontrollers of promising features are available in the market, using which WSNode can be designed for dedicated applications. Emphasizing the promising features of Wireless Sensor Network and its suitability for realization of precision agriculture, it is proposed to undertake the research work of development of Wireless Sensor Network (WSN), based on Zigbee technology, to monitor various environmental parameters of polyhouse such as humidity, temperature and light intensity etc. The results of on-site implementation are interpreted in this paper.

2. DESIGNING OF WIRELESS SENSOR NETWORK FOR MONITORING OF ENVIRONMENTAL PARAMETERS OF THE POLYHOUSE

As discussed earlier, Wireless Sensor Network is designed to monitor environmental parameters such as humidity, temperature, light intensity etc of polyhouse environment. According to the general architecture of the Wireless Sensor Network, it consists of Wireless Sensor Nodes and base station (BS). It is found that, reliability of Wireless Sensor Network, significantly depends upon the features of the Wireless Sensor Nodes (WSNode). Therefore, ensuring embedded technology, both hardware as well as firmware of wireless sensor node is designed to monitor humidity, temperature and light intensity. Moreover, the coordinator is also designed and interfaced to the base station. The details regarding designing issues of hardware and software of both WSNode and base station are described through following sections.

2.1 HARDWARE

2.1.1 Designing of Hardware for Wireless Sensor Node:

The Fig.2 depicts the block diagram of the Wireless Sensor Nodes. However, the circuit schematic is presented in Fig.3. On inspection of Fig.2 and 3, it is found that, the digital part, comprising computing unit, display unit and RF communication unit etc, is common for these three parameters. However, rest of analog parts are dedicatedly designed and deployed for each Wireless Sensor Node (WSNode). In fact, there are 9 WSNodes and one coordinator. However, the architecture of all WSNodes is identical. The architecture of coordinator is slightly different than that of WSNode. To conFig.all the nodes and coordinator Digi corporation provides an IDE X-CTU. Following sub-sections discuss the details about designing issues.

- **Sensor Array**:

The wireless sensor node is designed to monitor polyhouse parameters, humidity, temperature and light intensity. For this purpose, it is necessary to deploy the sensors of promising feature. Therefore, the sensor modules SY-HS 220, LM-35 and BPW 34 availed for monitoring of humidity, temperature and light intensity respectively. The details regarding these sensors are highlighted through following sub sections.

Humidity Sensor (SY-HS 220): Humidity is one of the important parameters of polyhouse requires to be measured. Humidity is measure of the water vapor content of the atmosphere [14]. The amount of water vapor in the air depends upon various environmental conditions. Normally, it is expressed in Relative Humidity (RH%). To measure humidity of polyhouse environments, a smart humidity sensor module SY-HS-220 is opted for the system under design. The photograph of humidity sensor SY-HS-220 is shown in the Fig.4. On close inspection of Fig.4, it is found that, the board consists of humidity sensor along with signal conditioning stages.

This humidity sensor is of capacitive type [15]. It comprises on board signal conditioner and other required stages, which make sensor rather more smart [16]. In addition to the humidity sensing unit the module consists of oscillator, wherein the sensor plays the role of timing capacitor. The frequency of this oscillator varies with the humidity [17]. Moreover, it also consists of AC amplifier, frequency to voltage converter and precision rectifier etc stages [18]. Incorporation of such stages on the board significantly helps to enhance the performance of the sensor. The humidity sensor used in this system is highly precise and reliable. It provides DC voltage depending upon humidity of the surrounding in RH%. This work with +5 Volt power supply and the typical current consumption is less than 3 mA. The operating humidity range is 30 to 90 RH%. For the interfacing purpose, the three pins named as B, W and R are provided. The assignment to these three pins is as, pin W DC output voltage, pin B ground and pin R- power supply (+5V). The humidity dependent dc voltage (V0) is extracted from this sensor module and then applied to analog part of the circuit for further processing.

Temperature Sensor (LM 35): In precision agriculture, temperature is also one of the most fundamental parameter to be measured. Temperature is not same for entire area of polyhouse, but it exhibit spatial as well as temporal variations within the domain of typical area [19]. Therefore, to collect Site Specific Variable data, it is decided to employ low cost highly precise monolithic temperature sensor LM 35. It exhibits good linearity over wide temperature range. The temperature sensor LM 35 provides the temperature dependent emf with temperature coefficient 10 mV/0C. The LM 35 does not require any external trimming for calibration. It provides, typically, the accuracy of ±1⁄4 0C at room temperature and ±3⁄4 0C over full, -55 to +155 0C, temperature range. It draws only 60 µA current [20]. Fig.5 depicts the temperature sensor LM 35. As presented in Fig.5, the LM 35 has three terminals, middle of which is output terminal and remaining two are employed to power the sensor. The output voltage observed (Vt), with the temperature coefficient 10 mV/°C, is extracted and fed to the signal conditioning stage of the analog part.

Light Intensity Sensor (BPW 34): Sun light plays vital role in the photosynthesis process of the plants. Therefore, monitoring of intensity of sunlight in polyhouse, wherein the crops are cultivated in controlled environmental conditions to ensure SSCM plays vital job for precision agriculturists. To measure intensity of light, highly reliable sensor, BPW 34 is employed. The Fig.6 shows the photograph of this sensor BPW 34. The circuit schematic is shown in Fig.7. As depicted in Fig.7, the sensor, PIN photodiode with high speed and high radiant sensitivity. It is sensitive to visible and near infrared radiation as well. The sensor is wired in reverse biased mode and resulting current (IL), produced by the sensor, allowed to pass through a resistor (RL) of 1 KΩ. The resulting emf is used for further analog design.

- **Signal Conditioning**:

The signal conditioning circuit is wired to provide parameter dependent voltage. Therefore, CMOS operational amplifier TLC 271 is used as a signal conditioner to interface the analog signals. The operational amplifier, TLC 271, exhibit very high input impedance and hence, it is most suitable to read the signal without any loss. An important characteristic of this TLC 271 is that it operates on single power supply and has rail to rail input as well as output [21]. The pin description of the TLC 271 is shown in Fig.8. The TLC271 operational amplifier combines a wide range of input offset voltage grades with low offset voltage drift and high input impedance. In addition, the TLC271 offers a bias-select mode that allows the user to select the best combination of power dissipation and ac performance for a particular application. These devices use Texas Instruments silicon-gate LinCMOS technology. This CMOS operational amplifier is configured as a buffer which helps to ensure isolation of the sensors. The features of this operational amplifier are well suited for single supply precision and battery powered applications [22], which are essential features of the wireless sensor nodes. The signals are conditioned and then subjected to further process of digitization and calibration.

- **Microcontroller Unit**:

As discussed earlier, the Wireless Sensor Node (WSNode), a primitive of Wireless Sensor Network, realizes an embedded technology, wherein microcontroller plays a key role. The salient features of microcontroller decide the reliability of the Wireless Sensor Node [23]. Therefore, deploying the microcontroller AVR ATmega 8L the computational part of the Wireless Sensor Node is developed. This microcontroller is small in size and exhibit low power consumption. It depicts, smart on chip resources by availing which an embedded design can be realized. Fig.9 depicts the pin description of AVR ATmega 8L [24]. The salient features of microcontroller AVR ATmega 8L, who helps to develop very smart embedded system is as below

- It has RISC instruction set with 32 general purpose working registers
- 8 Kbytes of In-system programmable flash with read while write capabilities
- 512 bytes of EEPROM
- 1K byte of SRAM
- 23 general purpose I/O lines
- A 6-channel ADC with 10-bit resolution
- A byte oriented Two-wire Serial Interface
- A programmable Watchdog Timer with Internal Oscillator
- A serial programmable UART
- A SPI serial port
- Five software selectable power saving modes.
- Internal and external interrupts
- Three flexible Timer/Counters with compare/capture modes

The deployment of such on-chip facilities of the AVR microcontroller such as ADC, I/O ports, memories etc. results in reduction of not only in complexity, but also in cost and time. It is known that the microcontroller AVR Atmega8L has six channels (ADC 0 to ADC 5) for Analog to Digital Conversion. However, the present Wireless Sensor Node (WSNode) is designed for monitoring of Humidity, Temperature and Light Intensity of polyhouse environment. Therefore, out of six, three channels, ADC 0, ADC 1 and ADC 2, which is configured in right justified mode is deployed for digitization of respective analog signals. The Fig.10 depict the interfacing of analog signals. The digital data is available in two resistors ADCH and ADCL, which is further packed by the expression given below.

$$DT = (ADCH*256) + ADCL \tag{1}$$

Thus, three analog voltages VH (Humidity), VL (Light Intensity) and VT (Temperature) are digitized and digital data are stored in variables Humidity, Light Intensity and Temperature respectively and deployed for further processing. Entire operation of the analog to digital converter synchronized through the software.

- **Wireless Communication Unit (Zigbee)**:

Wireless communication is the prime need of Wireless Sensor Network. For present WSNode, the RF section is designed about Zigbee series 2 devices launched by Digi Corporation and operates within ISM band and supports IEEE standard 802.15.4 [25, 26] shown in Fig.11. Low-Rate Wireless Personal Area Network protocol (LR-WPAN) for Wireless Sensor Networks (WSN) or for mesh networking use ZigBee. This allows addressable communications between nodes. Data may be sent to individual nodes (point-to-point), or to all nodes in range (point-to-multipoint) using a broadcast address. To ensure wireless communication, the Zigbee is interfaced to microcontroller in UART mode.

It known that, the Zigbee is a programmable RF module. For programming of the Zigbee device, the Digi Corporation has provided very smart IDE called “X-CTU”. Therefore, X-CTU is deployed for programming of Zigbee device in desired mode. Each Zigbee is programmed with respective node ID and establish the communication with the coordinator.

The salient features of this zigbee device are as mentioned below:

- RF data rate: 250 Kbps
- Operating frequency: 2.4 GHz
- 63 mW (+18 dBm) North American version
- Indoor/Urban range: Up to 300 ft (90 m)
- Outdoor/RF line-of-sight range: Up to 1 mile (1.6 km)
- Interface data rate: Up to 115.2 Kbps
- Receiver sensitivity: -100 dBm (all variants)
- 2mW (+3 dBm) boost mode

Thus by this embedded system, Wireless Sensor Node, the humidity, temperature and light intensity dependent signal is produced and transmitted towards the receiver installed at the base station.

2.2 DESIGNING OF HARDWARE FOR BASE STATION

Wireless Sensor Network plays vital job of realization of precision agriculture, which requires sophisticated electronic instrumentation that monitors the information of environmental parameters within the polyhouse [27] According to general architecture of Wireless Sensor Network, it exhibits widely spread Wireless Sensor Nodes (WSNodes), Coordinator and the Base Station (BS), which is established about personal computer. The PC is friendly interfaced to monitor and process the information collected by the Wireless Sensor Network [28]. The PC is connected with coordinator by using RS 232 interface. As discussed earlier, Nine WSNodes for monitoring of humidity, light intensity and temperature of polyhouse environment are designed. These Wireless Sensor Nodes collaboratively collect the information in respective domain and broadcast the same towards coordinator [29]. Moreover, to receive this broadcasted information the coordinator unit is also designed. In fact, any one of Wireless Sensor Node can be used as coordinator node because the coordinator has same structure with the sensor node except sensor module. Sensor node reveals the capacity of sensing, processing and broadcasting the data, where as coordinator node receive the data and communicates to base station [30]. This coordinator node of the WSN is responsible for the establishment of a network, information reception, aggregation, processing and sending control instructions and implementation. Therefore, coordinator node is key component in Wireless Sensor Network [31]. For present WSN, it is assumed that, no matter where the user is, the coordinator will always be connected to the monitoring center. It is known that, according to architecture of WSN the Base Station (BS) is composed of PC to which the coordinator node is interfaced. In fact, the coordinator is also equipped with the Zigbee module. Fig.12 depicts the block diagram of the Base Station (BS). For base station, Site Specific Data Monitoring (SSDM) Graphics User Interface (GUI) is designed and described at next article. Thus, smart base station is designed and configured to realize the establishment of the wireless sensor network.

2.3 FIRMWARE

The research work undertaken emphasizes the development of Wireless Sensor Network (WSN) for Precision Agricultural (PA) applications. As discussed earlier, the WSNodes, End Devices as well as Coordinators, reveal the embedded philosophy, wherein both hardware and firmware should be co-designed. The present WSN comprises nine WSNodes, designed to monitor the humidity, temperature and intensity of light of the polyhouse environment. Therefore, firmware is designed for all WSNodes & co-ordinator as well and devices are programmed with following firmware.

- Development of firmware for WSNode.
- Development of firmware for Base Station.

2.3.1 Development of Firmware for WSNode:

The WSNode of WSN realizes the embedded technology, wherein entire hardware is designed about microcontroller AVR ATmega 8L. Therefore, for the synchronization of operations, the firmware is required. Employing CodeVision AVR, an IDE, the firmware is developed in embedded C environment. The flash of the microcontrollers are programmed by using SinaProg 1.3.5.6, which supports USB based programmer. The software developed for measurement of humidity, temperature and light intensity consists of various functions. Along with the main program the firmware comprises various modules developed for specific tasks. Following are the modules developed and used in the program with proper sequence.

- Initialization of LCD [lcd_init( )]
- Character display [lcd_display]
- Analog to digital conversion [ADC (channel)]
- Calibration to humidity [data_from_Channel_0]
- Calibration to light intensity [data_from_Channel_1]
- Calibration to temperature [data_from_Channel_2]
- Decimal to BCD and ASCII conversion [(dec-bcd)]
- Parameter value display [LCD( )]
- Configuration of LCD[LCD cmd ( )]
- Sending data to LCD[LCD data( )]
- Serial communication [UART()]
- Delay Function [Msdelay( )]

The encryption to avoid network attack is also realized in the firmware.

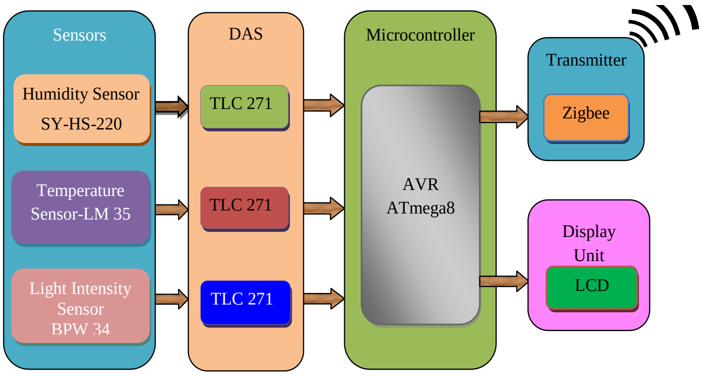

Fig.2. Block diagram of Wireless Sensor Node (WSNode)

2.3.2 Development of Firmware for Base Station:

The present work is to develop of Wireless Sensor Network (WSN) for monitoring of environmental status of the high-tech polyhouse, wherein the human interface is at the base station located at control cabin. Generally, agriculturists have less knowledge of computer hardware and software as well. Therefore, display of data on computer monitor in well understandable format is the need of hour. Considering this fact into account, the smart Graphical User Interface (GUI) is developed and installed on the base station by employing VB (Visual Basic) platform. Deploying required resources of the Visual Basic Environment, a Graphical User Interface is designed to demonstrate the site specific data of the high tech polyhouse. The photograph of the GUI is depicted in the Fig.13. On inspection of the Fig.13, it is found that, GUI is designed for Nine WSNodes numbered as WSNode 1 to WSNode 9. Each WSNode collects the data regarding three parameters; the Relative Humidity (%RH), Light Intensity (LUX) and Temperature (oC). On the top left corner the date of implementation is displayed. At the top the title is displayed. The packet given by the coordinator node are associated with the node ID and parameter ID as well. On receiving data, it sorted with respect to the WSNode number and parameter ID. The data related to respective parameters are communicated to window of the respective node and displayed.

Thus the data is collected and demonstrated in real time, which would be suitable for precision farmers. Moreover, a separate database is also created to store the data for further processing and deterministic management.

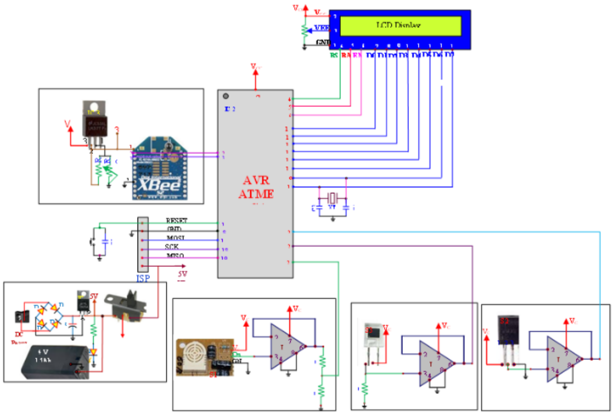

Fig.3. Circuit schematic of Wireless Sensor Node (WSNode)

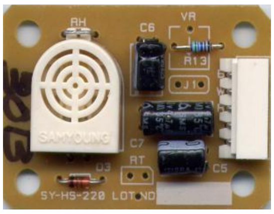

Fig.4. Humidity Sensor module SY-HS-220

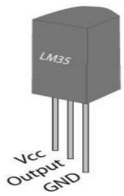

Fig.5. Temperature sensor LM 35

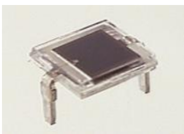

Fig.6. Light Intensity sensor (BPW 34)

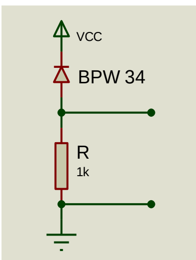

Fig.7. Circuit arrangement for Light intensity sensor BPW 34

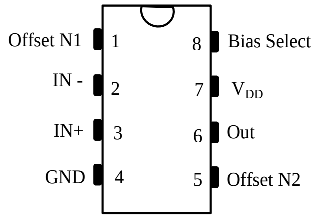

Fig.8. Pin description of TLC271

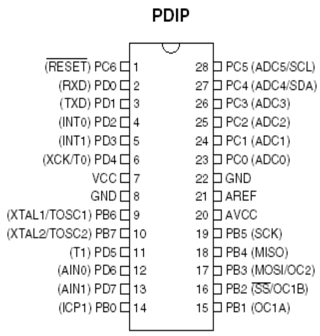

Fig.9. Pin description of AVR Atmega8L

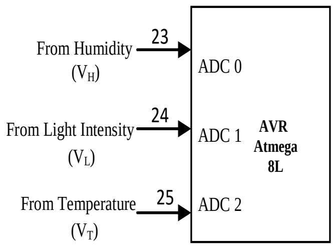

Fig.10. Circuit arrangement for interfacing analog signals

Fig.11. RF Module the Zigbee

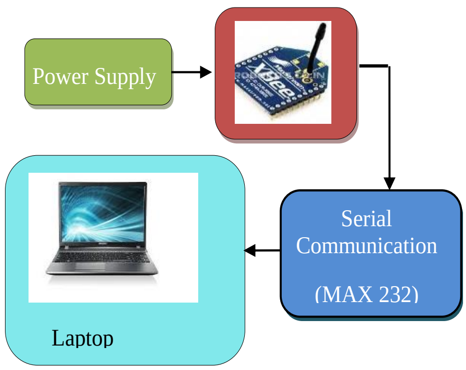

Fig.12. Block of the Coordinator of WSN

Fig.13. The Photograph of GUI developed in VB environment to demonstrate the Site-Specific Data Collaboratively collected by the WSNodes of the WSN designed for Polyhouse

Fig.14. Experimental arrangement for calibration of WSNode for Humidity in RH%

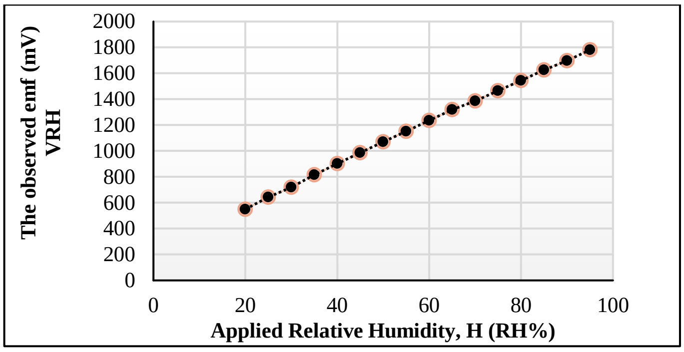

Fig.15. The graph of observed humidity dependent potential (VRH) against applied relative humidity

3. CALIBRATION OF WIRELESS SENSOR NODES

The wireless sensor nodes under investigation interact with the physical world, read the signal and process into real units. Hence, it is essential to calibrate the system to represent the values of the parameters more precisely. Each WSNode is designed for monitoring of relative humidity, temperature and light intensity of polyhouse environment. These parameters have their own characteristics and therefore, the WSNodes are separately calibrated for these parameters. The process of calibration is discussed through subsequent points. Therefore, the system is standardized, in the beginning, and then implemented for which it has been designed.

3.1 CALIBRATION OF WSNODE FOR RELATIVE HUMIDITY (RH%)

As discussed earlier, there are nine nodes. Therefore, each node must be calibrated for humidity in RH%. For present system humidity sensor SY-HS-220 is used. It produces humidity dependent voltage in milivolt range. For calibration, the humidity chamber, model Gayatri Scientific Ltd. Mumbai is used. In the beginning a humidity dependent voltage is measured for entire range from room temperature conditions to the condensation of water. The experimental arrangement is shown in Fig.14. At normal condition the output voltage observed is 1.43 V, whereas that of at saturation is 3.3V. However, the reference voltage used for digitization of the signal is 2.56 volt. Therefore, by employing suitable hardware, the signal is constrained within above limit. So that, it could be accommodated within the specified range. This also helps to avoid the system from saturation for elevated level of humidity. In this way, the range of voltage is 719 mV at room temperature and at 100% saturation of air is 1.60 volt. This confirms that the system never gets saturated for high humidity level.

Further, for precise calibration, the humidity of different values are applied between 30 to 90 RH% to sensor and data regarding humidity dependent emf (VRH) is recorded. The observed voltage (VRH) is plotted against applied humidity in %RH and shown in Fig.15. The graph depicts linear variation. Using least square fitting process, the standard regression process, the data is analyzed and fitted to straight line. The regression process results into the expression 1.

$$\text{Humidity (H) (RH\%)} = (\text{VRH} - 300)/14.83 \times 100 \qquad (2)$$

Where, VRH is the humidity dependent emf produced by the system under investigation.

The expression 1 is used in software and ported into each WSNode. Further, to validate the performance, the system is also implemented for measurement of the humidity from 30 to 95 RH%. Deploying standard humidity meter, Gayatri Scientific model serial No. 0020, and applying controlled humidity to the system through the standard humidity chamber, the performance of the system is investigated. The humidity values shown by the system under investigation and that of obtained from standard humidity meter, Gayatri Scientific model, are presented in Table.1.

From Table.1, it is found that the humidity data obtained from the present system and that of shown by standard instrument are closely matched. This supports the standardization process. The WSNodes are having exactly same hardware and software as well. Therefore, all nodes are calibrated to relative humidity and deployed in the wireless sensor network (WSN) designed for site specific data monitoring of high-tech polyhouse environment.

Table.1. Humidity data shown by system under investigation and that obtained from standard humidity meter

Humidity shown by the standard humidity chamber RH%	Humidity shown by the System under investigation in RH%
30.00	29.90
35.00	34.96

40.00	39.98
45.00	45.05
50.00	50.01
55.00	54.97
60.00	59.92
65.00	65.02
70.00	70.03
75.00	75.01
80.00	80.00
85.00	85.02
90.00	90.05
95.00	95.01

3.2 CALIBRATION OF WSNODE FOR TEMPERATURE (^{0}C)

In case of polyhouse, wherein the crops are grown in controlled environment, the temperature is equally important parameter. For present system, the monolithic temperature sensor LM 35 is used. It produces temperature dependent voltage in mili Volt range. It exhibits linear characteristics with temperature coefficient of 10mV/0C [32]. Following procedure is adopted for calibration of WSNode to the temperature in degree Celsius. The experimental arrangement for calibration of temperature is depicted in Fig.16.

In the beginning, for calibration of the system to real unit, the degree Celsius, the temperature dependent emf (VT) is measured and plotted against temperature from 25oC to 95oC. The least squares method of curve fitting is employed. The calibration curve is depicted in Fig.17. On inspection of Fig.17, it is found that the system exhibits good linearity for temperature within the range of investigation. By adopting process of regression, the empirical relation 2 is obtained

Temperature (t) OC = ((*VT* -95.11)/9.282)*100 (2)

where, *VT* is temperature dependent emf.

The expression 2 is used in software and ported into each WSNode which executes to produce continuous values of temperature in degree centigrade. Further, the system is also standardized with standard thermometer. The values of temperature shown by the standard digital thermometer and that of shown by present system are tabulated and presented in Table.2. The close match of the temperature values supports the reliability of hardware and software design. Thus, all WSNodes are calibrated to the temperature in 0C and deployed.

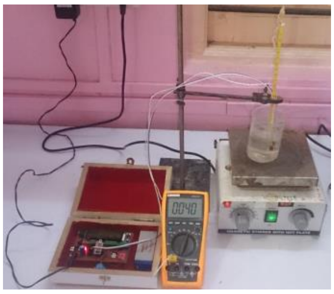

Fig.16. Experimental arrangement for calibration of the WSNode for temperature in ºC

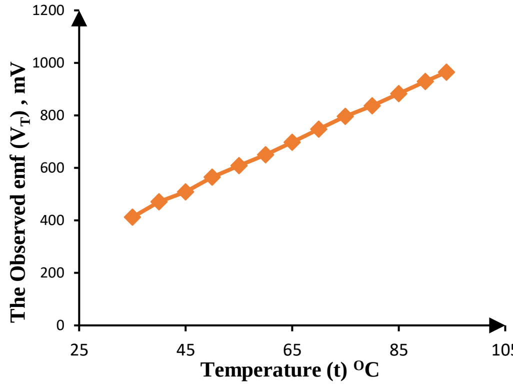

Fig.17. The Graph of Observed emf (V_T) in mV against applied Temperature in ºC

Table.2. Temperature data shown by system under investigation and that obtained from standard thermometer

Temperature shown by standard thermometer in ^{0}C	Temperature shown by system under investigation in ^{0}C
30.00	30.01
35.00	35.05
40.00	39.98
45.00	45.05
50.00	50.00
55.00	54.99
60.00	59.96
65.00	65.02
70.00	70.03
75.00	75.01
80.00	80.00
85.00	85.03
90.00	90.04
95.00	95.02

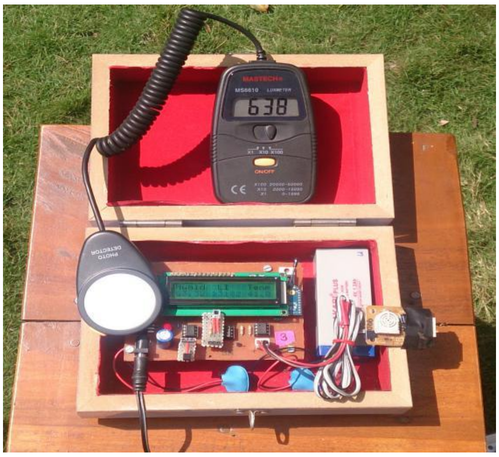

Fig.18. Experimental arrangement for calibration of WSNodes for Intensity of Sun Light in LUX using standard LUX meter Mastech make MS6610

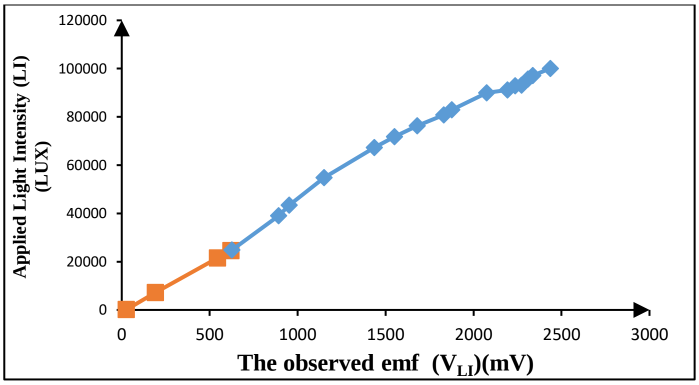

Fig.19. The graph of intensity of applied light (LUX) against observed emf VLI (mV)

Table.3. Light Intensity data shown by system under investigation and that of obtained from standard LUX meter

Time	Light Intensity data shown by system under investigation (LUX)	Light Intensity obtained from standard LUX meter (LUX)
10.00 a.m.	2568	2566
11.00 a.m.	3988	3978
11.45 a.m.	4998	4996
11.50 a.m.	5128	5130
11.55 a.m.	5367	5368
12.00 a.m.	5559	5560
12.05 p.m.	5559	5559
1.00 p.m.	4352	4353
1.30 p.m.	3332	3334
2.00 p.m.	2712	2712
3.00 p.m.	2293	2296
4.00 p.m.	1265	1270
5.00 p.m.	866	868

3.3 CALIBRATION OF WSNODE FOR LIGHT INTENSITY (LUX)

Present research work emphasizes the development of wireless sensor network (WSN) for high tech polyhouse application, wherein intensity of Sun radiation is monitored. The scientific unit to express the light intensity is LUX. Following procedure is adopted to calibrate the WSNode in the unit of LUX. Employing standard LUX meter the WSNodes are calibrated. The light radiations of variable intensity are allowed to incident perpendicular to the surface of the sensor. To measure intensity of light the standard LUX meter model Mastech make MS6610 is deployed. The experimental arrangement is shown in Fig.18. Using this LUX meter, intensity of light is measured. The instantaneous emf (VLI) produced for various light intensities (LI) in the LUX are recorded. The experiments carried out repeatedly. The emf (VLI) values are recorded and plotted against Light Intensity (LI) and the plot is depicted in Fig.19. This graph is employed to realize the precise calibration. On inspection of the graph, it is found that, the emf produced by the system depicts good linearity for lower range of light intensity. If light intensity increases from 39000 LUX, then the trend of increase in the emf deviates from linearity. This can be attributed to the fact that for lower intensity of light the photon incident on the sensor is less. As intensity of sun's radiation increases the concentration of photons increases with logarithmic scale [33, 34, 35]. Therefore, for lower range of light intensity the trend of increase in the emf is almost linear. However, as shown in the Fig.19 the trend of increase in the observed emf with increase in the light intensity suggests logarithmic relation. The observed data is subjected to process of regression. As depicted in Fig.19 the graph has two regions. Therefore, two region calibration process is adopted. The process of regression is applied separately for two regions and following empirical relations are obtained.

$$\text{Light Intensity (LI) LUX} = ((40.98 * VLR)-880.8) \quad (3)$$

$$\text{Light Intensity (LI) LUX} = ((56599\ln(VLR)) - 34342) \quad (4)$$

The present WSN is establishment for monitoring of environment of polyhouse, wherein the Sun's radiations are sufficiently low. Therefore, instead of elevated region of light intensity, the lower region is considered. For lower region the empirical relation (equation 3) is valid and hence it is availed in the software for further processing. On execution of this expression into software, each WSNode provides the data of light intensity in unit of LUX. For validation of the calibration process, the readings of light intensities shown by the system under investigation are measured. The similar measurements are also taken with standard LUX meter. The observations shown by the system and that of obtained from standard LUX meter are presented in Table.3. On inspection of Table.3, it can be said that the results obtained from standard LUX meter and that of shown by the system are closely matched. This supports the preciseness of the calibration. All WSNodes have been calibrated to unit of LUX and employed to establish the WSN under investigation.

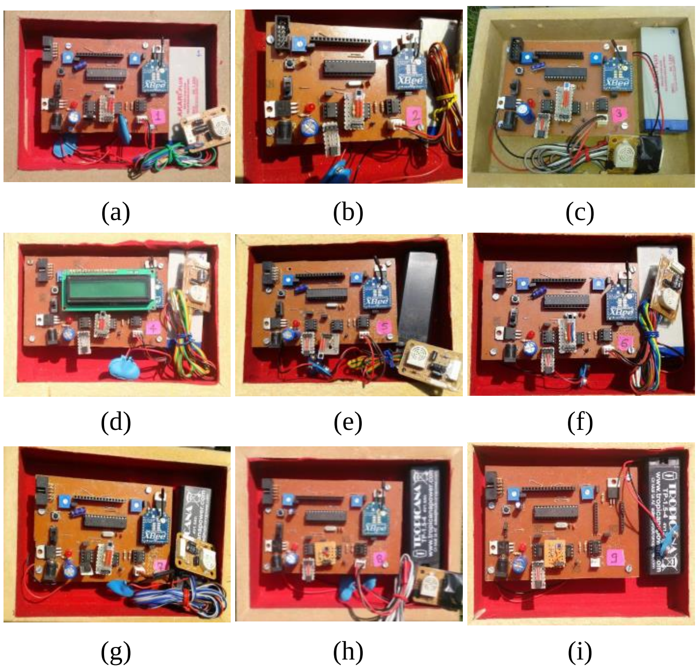

Fig.20. The Photograph of WSNode 1 to WSNode 9 designed for development of WSN for monitoring environmental parameters of High-Tech Polyhouse

Following the procedure discussed above, the WSNodes are calibrated for three parameters the humidity in RH%, the light intensity in LUX and temperature in 0C. The successfully calibrated and standardized WSNodes are deployed for establishment of WSN for dedicated applications. Deploying the WSNodes and base station the wireless sensor network (WSN) is established.

4. ESTABLISHMENT OF WIRELESS SENSOR NETWORK

Present work realizes the designing of WSNodes which depicts embedded technology, wherein both hardware and firmware is designed. After designing, present work ensures the monitoring of various parameters of polyhouse environment and therefore all nodes are systematically calibrated typically for three parameters the temperature, the humidity and the light intensity. Thus, after calibration the designing process is completed and nodes are ready for establishment. The Wireless Sensor Nodes (WSNodes), by designing, both hardware and firmware and calibration are made ready for establishment of wireless sensor network. Moreover, the coordinator node is also designed and made available for the same. In fact, the system is designed for 10 WSNodes wherein 9 nodes are configured as end device and one node is configured as coordinator. The end devices are named as WSNode 1, WSNode 2, WSNode 3, WSNode 4, WSNode 5, WSNode 6, WSNode 7, WSNode 8 and WSNode 9. The WSNodes are depicted in Fig.20(a-i).

Thus, the infrastructure the WSNode and base station, required for dedicated WSN is prepared. Now, the Wireless Sensor Network is ready for implementation for which it has been designed.

Fig.21. Photographs of Polyhouses, selected for implementation of WSN. located at Kondigare - Jaysingpur Tal shirol Dist Kolhapur

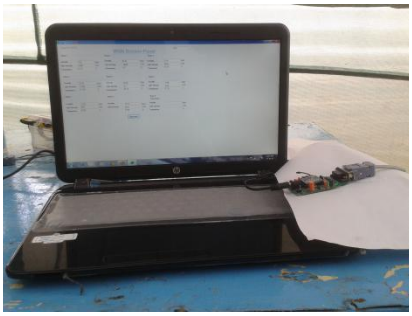

Fig.22. Photograph showing establishment of Base Station of WSN

Fig.23. The internal environments of Polyhouses dedicated for Roses of different varieties

Fig.24. Hanback Electronics Made Ubiquitous WSN at a glance

Fig.25. Photograph showing establishment of Base Station of WSN-HBEX

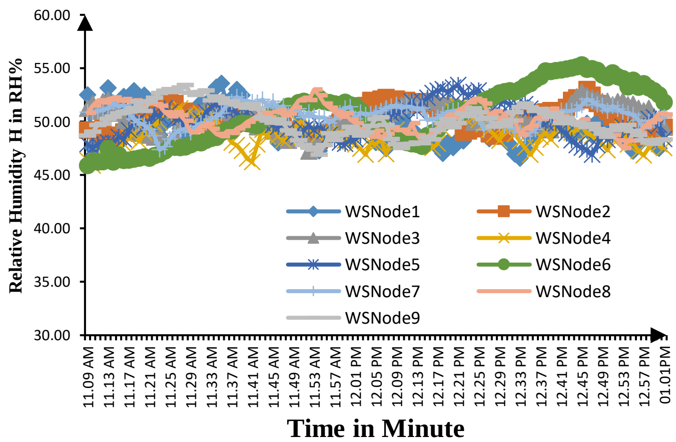

Fig.27. The graph of Relative Humidity (RH%) against Time (Minute) for WSNodes 1 to WSNode 9

Fig.26(a-f). The positions of typical WSNodes and Motes

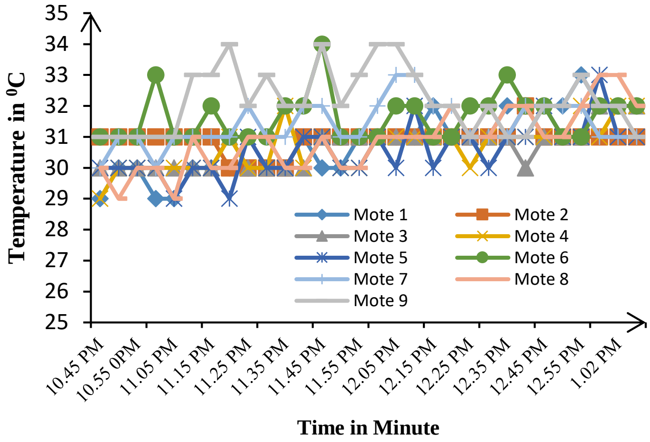

Fig.30. The graph of temperature against time plotted for Mote 1 to Mote 9 of WSN-HBEX

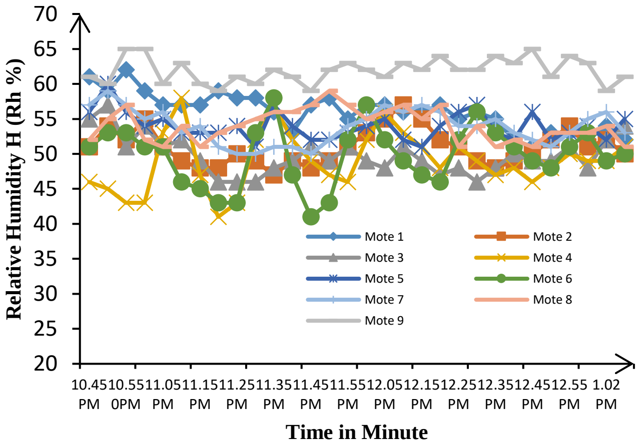

Fig.28. The graph of Relative Humidity (RH%) against Time (Minute) shown by the motes of WSN-HBEX

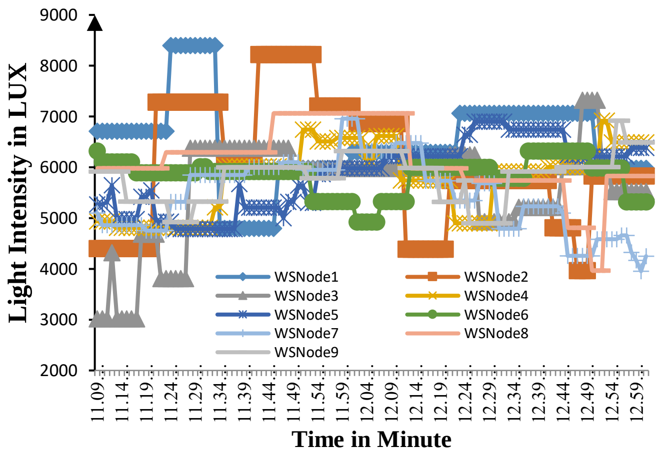

Fig.31. The graph of Intensity of Light in LUX against time plotted for WSNode 1 to WSNode 9 of WSN

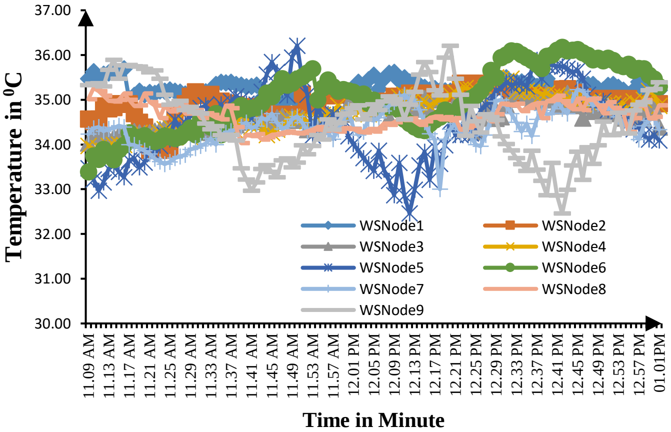

Fig.29. The graph of temperature against time plotted for WSNode 1 to WSNode 9 of WSN

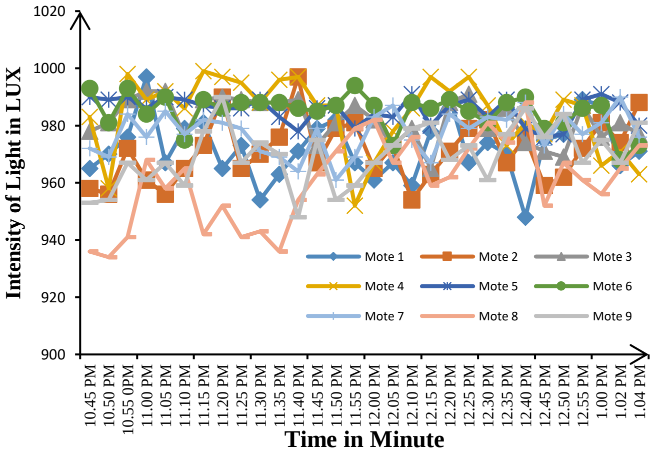

Fig.32. The graph of Intensity of Light in LUX against time plotted for Mote 1 to Mote 9 of WSN-HBEX

5. IMPLEMENTATION OF WIRELESS SENSOR NETWORK (WSN) WITHIN HIGH-TECH POLYHOUSES

Indeed, the Wireless Sensor Network (WSN) is designed dedicatedly for monitoring of environmental parameters of the high-tech polyhouse. Therefore, with the view to ensure Precision Agriculture (PA), the Wireless Sensor Network is deployed for monitoring of environmental parameters, the humidity, the temperature and the light intensity of polyhouse. The the present WSN is implemented at Polyhouse of Shrivardhan Biotech, located at A/P. Kondigare- Jaysingpur Tal. Shirol Dist Kolhapur at which the precision farming is ensured and the results of implementation are interpreted. The village Kondigare is located nearby Jaysingpur. The external view of the said polyhouse is depicted the photograph shown in Fig.21. The Wireless Sensor Network (WSN), comprising Wireless Sensor Nodes (WSNodes) and Base Station (BS) is established by deploying star topology and implemented to monitor the environmental parameters in said polyhouse. The experimental arrangement depicting the establishment of Base Station is shown in Fig.22. The area of polyhouse is about 1089 sq.ft and has rectangular in structure. The internal view is shown in Fig.23. The agriculturist is cultivating Rose in this polyhouse.

However, standardization of the system to the desired specifications is an important step of the electronic system design. Therefore, to compare the performance of the WSN under investigation, the standard Wireless Sensor Network is employed. It is designed and launched by HANBACK Electronics, Korea under the model name as HBE-Zigbex-II [36]. It is ubiquitous sensor network designed about AVR ATmega 128L and operating in TinyOS environment. For demonstration of the data, the GUI is developed in NS2 environment. It is highly suiTable.for monitoring of humidity, temperature and light intensity. The wireless communication module CC2420 is used which operates on 2.4 GHz. The system is having 10 motes, with the Mote ID as Mote 0 to Mote 9 depicted in Fig.24. Moreover, for present discussion, the mote 1 to 5 is considered. Moreover, simultaneously two WSNs; one WSN designed for the purpose and second the standard WSN made by Hanback South Korea, have been established. In order to distinguish them, the WSN under investigation is named as “WSN”. However, the WSN from Hanback is named as “WSN-HBEX”. Therefore, hereafter the name WSN-HBEX is used for standard WSN made by Hanback, Electronics. The motes of this standard WSN-HBEX and the WSNodes of the WSN under investigation are deployed systematically, to cover entire area of the polyhouse environment. This WSN-HBEX has its own Base Station depicted in the Fig.25. Therefore, the parameter values collected by WSN and WSN-HBEX are recorded and the results are availed for interpretation. The positions of typical WSNodes and motes are shown in the Fig.26(a)-(i).

5.1 MONITORING OF HUMIDITY OF ROSE POLYHOUSE

The polyhouse is having plants of Roses of various types. The WSN is implemented and humidity data is taken against time from 11.09 am to 1.00pm. From investigation of this instantaneous data given the WSN under investigation, it is found that, the humidity of the polyhouse environment is about 50 RH% and is almost constant during the period of investigation. It is known that, the WSNodes are distributed to realize the Site specific Variability (SSV) in the environment of the polyhouse. Each WSNode collects the humidity data of its own site. To ensure the comparative study of the data collected by all WSNodes are plotted against time and depicted in Fig.27 and 28. On inspection of these graphs, it can be said that, the humidity value observed for different cells is different. Moreover, the Trend of its instantaneous variation is also different for different cells. This ensures the site specific variability (SSV), which is expected for precision agriculture. Therefore, to ensure precision agriculture, the precision farmers should take care of this site specific variability in the environmental parameter and provide reliable Site Specific Crop Management (SSCM).

The standard WSN, WSN-HBEX is also deployed and the humidity values shown by the motes of the WSN-HBEX are recorded and plotted against time in Minutes. The graph of relative humidity against time is presented in the Fig.28. On inspection of this graph, it can be said that, the WSN collects the humidity data from respective sites. The values observed reveal the site specific variability. On investigation of results obtained from the WSN under investigation and that of shown by the WSN-HBEX, it can be concluded that, the WSN under investigation shows performance with great reliability and preciseness.

5.2 MONITORING OF TEMPERATURE OF ROSE POLYHOUSE

The Wireless Sensor Networks are deployed to monitor the temperature of the Rose Polyhouse. The nodes, WSNodes of WSN and Motes of WSN-HBEX, are designed for measurement of temperature of the environment and precisely calibrated for temperature in degree centigrade. The instantaneous values of temperature given by both WSNs are recoded and plotted against time. The graph of temperature against time is depicted in Fig.29 and Fig.30, respectively for WSN and WSN-HBEX. The average temperature of the polyhouse is about 34 to 45 degree centigrade. The temperature values shown by the WSNs ensure SSV as needed for Precision Agriculture.

6. MONITORING OF INTENSITY OF LIGHT OF ROSE POLYHOUSE

The Wireless Sensor Networks are deployed to monitor the intensity of the Sun light penetrated into the Polyhouse. Both WSNs are deployed simultaneously and intensity of sun light at different sites of the polyhouse is collected at the base stations of both WSN. The instantaneous values of the intensities of the light are recorded and plotted. The Fig.31 and 32 present the graphs of light intensities (LUX) against time. These two Fig.reveal the fact that the trends of variation of LI shown by both WSNs are almost identical. From inspection of the graphs of light intensities it is found that, the values of light intensities are not constant. The average values of the same measured for typical cell is also not stable. The graph reveals continuous variations in the light intensities. On inspection of such graphs obtained for temperature as well as humidity, there is slight variation in the parameter values from their own average value. That means the value of temperature and humidity is almost same within the region of the cell. However, the value light intensity suddenly changes. This may be due to the fact that the area to be considered for determination of light intensity. In fact, various factors such as human interference, shadow of the leaves, fog, clouds in the sky, season of experimentation, change in the internal environment due to fog produced due control the humidity level etc affect of the intensity of sun radiations falling on the sensor. Therefore, the graphs are showing fast variations in the intensity of sunlight.

7. CONCLUSION

Emphasizing need of precision agriculture wireless sensor network for monitoring of humidity, temperature and light intensity of the polyhouse is designed and implemented. The present WSN comprises nine nodes and the coordinator node, which depicts the philosophy of embedded system design. The WSNodes have been designed and successfully calibrated to the respective units. Each WSNode is associated with the own networking ID and establishes the communication with the respective ID. The wireless sensor network under investigation is implemented for monitoring of environmental parameters, such as the humidity, the temperature and the intensity of light etc, at Rose polyhouse. Simultaneously, the standard WSN called WSN-HBEX is also deployed. The base stations of both WSNs are also established separately in the campus. The WSN works in Star topology. The GUI is also facilitated to store the data in real time. The values of parameters, collected by the WSNodes and motes are presented. On inspection of the parameter values, it is found that, data exhibit site specific variability (SSV), which definitely helps to realize site specific crop management (SSCM). The values of the parameters given by the system under investigation and that of obtained from standard WSN are closely matched. This good agreement of the data given by the WSN with that of obtained from WSN-HBEX reveals that, the WSN designed for present investigation is highly reliable and precise. It can be concluded that, the wireless sensor network is successfully designed and implemented to monitor the environmental parameters of the polyhouse under investigation.

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