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Design and Implementation of Sensor Network to Monitor Environmental Parameters of Blower Unit of Cotton Yarn Manufacturing Industry

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Abstract - In textile industry, monitoring of the environmental parameters such as temperature and humidity is essential. To maintain the quality of the cotton yarn, the environmental temperature and humidity is maintained at the précised level in textile industry. In fact, these parameters depict site specific variability (SSV). To play with such site specific data, deployment of the Wireless Sensor Network is most suitable solution. To monitor such parameters the wireless sensor network is established, wherein the wireless sensor nodes play a vital role. With the greater reliability and flexibility the wireless sensors nodes are designed, wherein ARM microcontroller, ARM LM4F120H5QR, is used as a core for computational task and RF transceiver module Xbee series-2, from DIGI International Inc, is used for Wireless Networking. Deploying embedded technology the sensor nodes have been designed for on-line monitoring of the two parameters such as, environmental temperature (^{0}C) and environmental humidity of the textile industry. The smart sensors, SY-HS-220 for humidity measurement and LM35 for temperature measurement are deployed. The signal conditioning and other analog part of the hardware is designed about CMOS based operational amplifiers MCP606. Ensuring the design of embedded system, both hardware as well as software is co-designed. Employing process of regression, the sensor nodes have been calibrated to the real units. The Refinement factor (R) is minimized and empirical relations are obtained. The empirical relations reveal the salient features of the sensor itself. The results shown by the nodes under investigation and that of obtained from standard instruments show close agreement. This reveals the reliability and accuracy in the hardware and software designed. Deploying such nodes and the coordinator, the wireless sensor network is established by employing Zigbee technology and implemented for monitoring of the dedicated parameters of the textiles industry. The results of implementation of WSN for monitoring of environmental parameters of textile industry are interpreted in present paper.
Keywords-- Sensor Node, Wireless Sensor Networks, XBee RF Module, ARM Microcontroller, Base Station.

I. INTRODUCTION

Recent advances in the electronics technologies results into revolutionary developments in fields of science and technology. Due to relentless efforts of scientists and technologists the fields such as Embedded Technology, Integration technology, communication technology, smart sensor design technology etc are pervasively growing and evolving innovative fields for research and developments [1-2]. On confluence of embedded technology and communication technology with computer technology, a novel field called Wireless Sensor Network is emerged [3]. Wireless sensor network provides new paradigm for sensing and disseminating information from various environments with a great potential to serve many and diverse applications [4]. The monitoring of various physical parameters such as temperature, fluid level, relative humidity, intensity of light, concentration of gasses dissolved in the atmosphere, vibrations, strain, soil moisture, industrial process parameters, pH and salinity of water etc plays commendable role in various sectors such as environmental pollution monitoring, high-tech agriculture, structural engineering, chemical and physical industries, transportation, military and defense, healthcare, forestry etc [5-9]. These physico-chemical parameters are depicting Site Specific Variability (SSV) and monitoring of such widely distributed parameters is challenging task. During early days, the wired networks have been deployed for monitoring of such parameters. However, the wired networks are not only infeasible for typical environment but also shows high cost, hardware complexity, hard to debug and upgrade. The wireless sensor network provides suitable solution to overcome the limitations of the wired system. The WSN is the application specific establishment of smart sensor nodes. The sensor nodes are systematically distributed over a geographical area of interest. The sensor nodes are intelligent and have capabilities such as sensing of physical environment, signal processing and wireless communication. Recently, an embedded technology, wherein smart devices such as microcontrollers of promising features are deployed as computing unit, helps to enhance the intelligence of the sensor nodes. Therefore, it becomes possible to design the intelligent, autonomous and energy efficient sensor nodes to facilitate the desired WSN. Emphasizing an implementation at textile industry, the WSN is designed and results of investigation are reported in this paper. Section 1 is of introduction. Section 2 is devoted for design and establishment of the WSN. Section 3 deals with the investigation of various WSN parameters. Results of on-site implementation are interpreted in section 4 and conclusion is given in section 5.

II. WIRELESS SENSOR NETWORK (WSN)

Wireless sensor network (WSN) is the distributed network of large number of wirelessly connected autonomous devices, called Wireless Sensor Nodes, which collaboratively collects the information about physical world and disseminates the same towards the

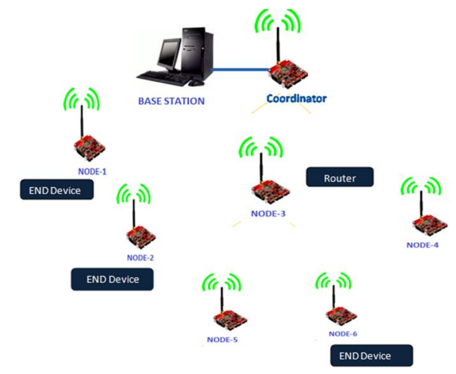

Figure 1: General Architecture of Wireless Sensor Network

monitoring stations called Base Station (BS) for the deterministic analysis and presentation [10-13]. The general architecture of wireless sensor network is shown in figure 1.1. The WSN is an infrastructure comprised of sensing, computing and communication elements, which provides the information about area and process of interest to the administrator, to ensure the sustainable management [14]. As depicted in figure 1, the WSN comprises following four components.

An assembly of distributed Wireless Sensor Nodes.
An interconnecting wireless network in suitable protocol.
A smart base station.
A set of computing devices required for data computation, co-relation, event, trending, status querying and actuations etc.

A. Development of Wireless Sensor Network for Industrial Applications

The processes of the textile industries were studied and it is observed that, to maintain the quality of the cotton yarn, the parameter

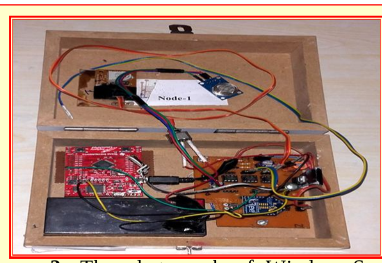

Figure 2: The photograph of Wireless Sensor Node

such as temperature and humidity etc of the environment, should be precisely controlled. To optimize the quality of the yarn, essentially, the temperature is maintained precisely at 32^0C [15,16]. The relative humidity of an environment should be controlled at 55%RH [17,18,19]. At present, for monitoring of temperature and humidity, electronic, monitoring units, are installed, wherein usually only local values of these parameters are displayed. This unit of textile industry is spread over wide area and the said parameters are depicting Site Specific Variability. To monitor the parameter values very few numbers of such devices have been deployed. Therefore, these rarely spaced monitoring units could not cover the area of textile industry. Moreover, normally these

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monitoring units are not networked. Therefore, it is essential to collect the data manually. This hardly provides the data in real time. Therefore, precision controlling of the temperature as well as relative humidity of the environment is not ensured. This may adversely affect the quality of the yarn. Therefore, textile industry is demanding electronic system to cater this need.

The Wireless Sensor Network can be suitably designed and implemented to monitor the various parameters, indoor as well as outdoor, of the textile industry, at control cabin. For establishment of the WSN to collect the site specific data, the five sensor nodes

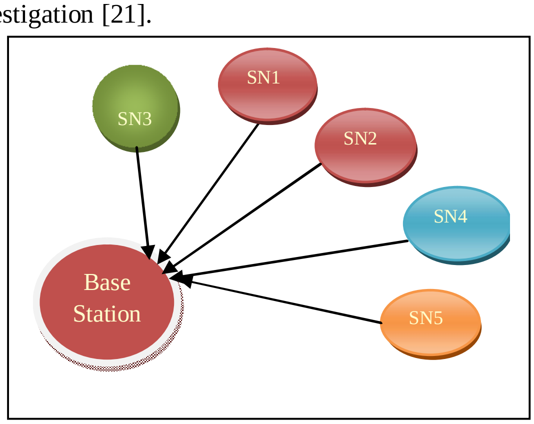
Figure 3: The photograph of Base Station with Coordinator

of promising capabilities have been successfully designed. In addition to this, to facilitate the Base Station, the inherent part of the WSN, a coordinator is also deployed. The Senor Nodes are identified with the name as Node1, Node2, Node3, Node4 and Node5. The photograph of the Sensor Node is shown in the figure 2. Moreover, figure 3 depicts the base Station. This coordinator is interfaced to the computer and the Base Station is designed and presented in figure 3. On inspection figures 2, it is found the sensor nodes are associated with the transducer interface modules, which comprises of an array of the sensors. To ensure autonomous operation, the nodes are facilitated with the chargeable battery. The Zigbee device is interfaced to the serial port of the microcontroller. The sensor nodes are encapsulated in box.

The coordinator, as shown in figure 3, is also separately designed. Figure 3, depict the organization of the Base Station [20]. The Node ID and Parameter ID are allocated to each of the nodes and process of assembling and disassembling of the packets is carried out. Thus, the WSN of five sensor nodes and the Base Station is developed and deployed for monitoring of the environmental parameters at the site of manufacturing of cotton yarn in the textile industry.

III. INVESTIGATION OF PARAMETERS OF THE WSN

It is emphasized to implement the WSN for monitoring of the industrial parameters. Therefore, the WSN of five nodes and the Base Station is established and implemented for the purpose for which it has been designed. Before implementation, the typical parameters of the WSN such as Received Signal Strength Indicator (RSSI), Link Quality Indicator (LQI), Power consumption etc, have been intensively studied and results of investigation are interpreted. These parameters are mostly useful for placement of the sensor nodes from the Base Station and gridding of the area under investigation as well. This also helps to predict about Quality of Service (QoS) of the WSN under investigation [21].



A. Experimental

The WSN parameters such as RSSI, LQI, Power consumption etc have been investigated. To measure RSSI and LQI, the each of sensor nodes are located at variable distance (d_N) from the Base Station. An IDE X-CTU is installed on the Base station to read the RSSI values of each node. The X-CTU gives RSSI of the SN either quantitatively in the unit of dBor in the terms of graphical display. The RSSI values (R_N) of the N^{th} node in measured in dB with respect to the distance (d_N) from Base station. The schematic of experimental arrangement is depicted in figure 4. The values of RSSI are recorded with the distance d_N and presented graphically.

B. Results and Discussion

It is known that, for performance analysis of the WSN the qualitative and quantitative analysis of the typical parameters is essential. Therefore, in present investigation, typical parameters, such as temperature and humidity etc have been investigated and presented in this section.

1) *Received Signal Strength Indicator (RSSI):* The Received Signal Strength Indicator (RSSI) is an important parameter of the WSN used to interpret the performance of the WSN. Therefore, the RSSI of each sensor node (SN) is measured, by using an IDE X-CTU, in dB with variable distance from Base Station. The RSSI values shown by each node is recorded and plotted against the distance from the Base station. The graph of RSSI values (R_N) against the distance (d_N) for all five nodes is presented in figure 5.The received signal strength indicator (RSSI) is a measurement of the power present in a received radio signal. Therefore, the RSSI values are negative numbers. From inspection the figure 5, it is found that, as distance (d_N) increases the RSSI values negatively increasing. This supports the fact that, the received signal strength is decreasing with increase in the distance. The Zigbee devices are deployed for wireless communication. The device is having dedicated antenna

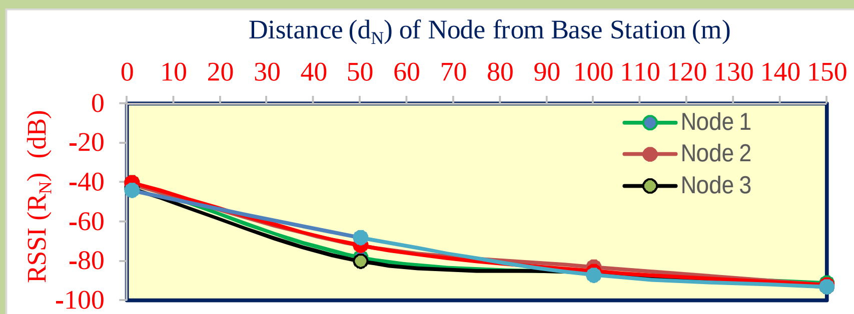


Figure 5: Graph of RSSI Values in (dB) of the Nodes deployed in the open environment against distance between node and the base station

and it is having its own radiation pattern. According to radiation pattern, the transmission strength and received strength systematically varies with the distance. According to the datasheet, for favorable communication of the data, the RSSI values should be in the range from 0 dB to -120 dB [22]. On inspection of the figure 5, it is found that the RSSI values of each node are in this limit. The RSSI values observed for fives nodes are in the range from -42 dB to -92 dB [23]. This is the acceptable range. This suggests the favorable communication is established in present WSN, realizing good quality of the service (QoS). These values of the RSSI are availed for establishment of the WSN within the industrial indoor as well as outdoor environment. For indoor deployment the range of RSSI is less than that of in open environment. The Link Quality Indication (LQI) is also measure of quality of the signal received at the base station. This depends upon the distance of Sensor Node and the Base station. The X-CTU IDE [24] can be used to study the LQI of the nodes.

2) *Power consumption* Generally, battery capacity is expressed in terms of Ah. It is an amount current drain out per hour at given voltage. For example, if the battery is having capacity of 12V and 1.33 Ah, and if current consumption of the circuit is 1.33Amp, then the life of battery is supposed to be one hour. If current consumption is less then it last for more period. However, said battery will be drained earlier for heavy current consumption. Using this philosophy, the expression for battery life is defined. Therefore, the battery life is given by

$$\text{Battery Life in (Hours)} = \frac{\text{Total power (Vx Ix h)}}{\text{Power consumption }(VxI_N)} \quad (1)$$

Where V is the voltage of the battery, I is maximum current capacity of the battery in Amperes and I_N the average current flows through the Node during active mode and h is the time in hour. Current flowing through the various parts of the nodes, including sensor array, is estimated to I_N =250mA for 12V. Therefore, from expression 1, the battery life is determined and it is about 5.32 hours.

Table 1: Rate of Packet transmitted by the Nodes

Sr.No.	Node	Rate of Packet transmitted per minute
1.	Node 1	20
2.	Node 2	25
3.	Node 3	30
4.	Node 4	35
5.	Node 5	40

3) *Rate of Packets Transmission:* In present WSN the Zigbee is used as RF module and it is operating according to IEEE 802.15.4 standards. According to these standards, the data rate is about 250 Kbps for short range communication. However, for present WSN, the sensor nodes have been configured by developing suitable firmware. In the firmware, a provision has been made to configure the rate of packet transfer. If all nodes communicate with the coordinator with same rate then the flooding may occur at the coordinator. To avoid the flooding the packet rate of the each node is kept different. The number of packets transmitted by the node per minute is predetermined. The packet rate of sensor nodes is presented table 1. As shown in table 1, the packet rate of Node 1 is configured for 20 packets per minutes. However, this packet rate is maximum 40 packets/minutes for Node 5. This variable packet rate of transmission helps to avoid the problem of flooding of data at the coordinator.

4) Loss of Data : The packet received by the coordinator is stored in the database. On the inspection of the database it is found that, the Sensor Node-1(SN1) transmits the 20 data packet/minute to the base station. The packets received at the coordinator are averaged over 60 minutes. It is found that, average receive rate is 17 packets/minutes. Similarly, for Sensor Node-2 the receive rate is 21 packets / minutes. The rate of loss of packets is approximately 3 to 4 packets per minutes. The Loss of data rate in percentage could be calculated by using expression 2.

$$\text{Data Loss (\%)} = \frac{\text{Packets received by the Base station}}{\text{Packets Transmitted by Sensor Nodes}} \times 100 \qquad (2)$$

It is found that, the data loss is only about 16% per minute.

IV. ON-SITE IMPLEMENTATION OF WSN UNDER INVESTIGATION

The major objective of the present research work is to design and deployment of the Wireless Sensor Network (WSN) for monitoring of indoor industrial environment. Emphasizing the features of the WSN, it is found that, the WSN is most suitable technology, which can be used for monitoring Site Specific and spatio-temporal data and management of the same. It is found that, in many industries monitoring and controlling of indoor environment is vital job. The quality as well as quantity of the products depends upon the environmental conditions. Unfavorable environment adversely effect on the Quality of Product (QoP). Therefore, indoor environment of the industry must be precisely monitored and controlled as well. As discussed earlier, the WSN is dedicatedly developed for monitoring of industrial environment and it is made ready for deployment. To ensure on site deployment various industries have been studied. Fabtech Group of Industries is performing pioneering job in establishment of renowned industries such as textile industries. This group of Engineers has established the textile industry at Ekatpaure near Sangola with title as “Fabtech Projects and Engineers Ltd (Textile Division), Ekhatpur, Tal SangolaDistSolapur”. The photograph (figure 6), showing internal view of phase-I of the txtile industry, at which the WSN under investigation is established. The indoor area of the Phase –I is 250m x 40 m (=10,000 sq.m.) wide. Therefore, monitoring the parameters of the indoor environment is very tedious task. Due to this wide area, it is found that, the environmental parameters are depicting Site Specific Variability (SSV). It is found that, the environmental parameters such as temperature and relative humidity are playing significant role on the process of manufacturing of the yarn.

Therefore, it is attempted to monitor these two parameters by using WSN under investigation.

The WSN under investigation is arranged in such a way that, it will cover entire area of the phase-I. According to the architecture of WSN, to realize the site specific variability, an area under consideration should be divided into the cells of typical area. It is

Figure 6: The photograph of internal view of Phase –I of the Fabtech Projects and Engineers Ltd (Textile Division), Ekhatpur, Tal Sangola Dist Solapur selected for implementation for WSN

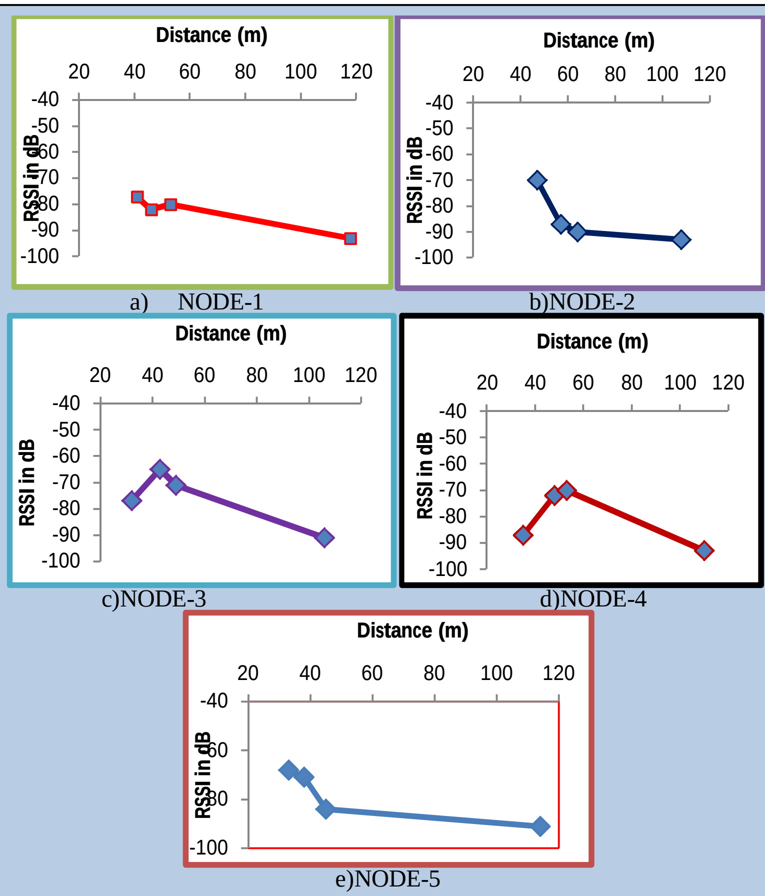


Figure 7 : The graphs of RSSI values (R_N) against the distance (d_N) for Node 1 – Node 5.

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supposed that, a Sensor Node is collecting the information of the respective cell. In fact, the phase-I is fragmented into four sections such as blower section, prefatory section, spinning section and ring conner section etc. Before implementation of the WSN under investigation for monitoring of indoor environmental parameters of the textile industry, the WSN parameter RSSI is investigated. As discussed earlier, the RSSI is one of the WSN parameters, which reveals the information regarding Quality of Service (QoS) [25]. For sustainable QoS of the WSN, the values of RSSI and Link quality should be essentially within acceptable limit. In fact, the RSSI values depends upon the battery power of the sensor node, distance between sensor node and that of Base Station, infrastructural interference, industrial machine interference and Line of Sight [26-28]. If RSSI value of the node is within the range of good quality communication then it could be fixed at that location. Otherwise, the sensor node may be healed from the network. To avoid the possibilities of healing of the sensor nodes, the data regarding RSSI values are recorded and presented in the figure 7. The RSSI values are decreases with increase in the distance. The RSSI of node 2, shown in figure 7 (a, b), also shown decreasing trend with increase in the distance. As depicted in figure 7 (c & d), it is found that, the RSSI values at lower distance (30 ft) is found less than that of at higher distance (40 ft). This can be attributed to the fact that, location of the node is partially hidden with respect to the Base Station. A huge machine of the textile process is as obstacle for wireless communication. Therefore, RSSI and link quality is less for these nodes. This supports the fact that, wireless networking is affecting due to infrastructural and machinery obstacles. The RSSI value of Node 5, which is in line of sight decreases with distance only. While deploying the WSN into phase-I, these sections are separately considered and within each section the WSN is established and the parameters such as temperature and relative humidity are monitored in real time. Thus Wireless Sensor Network under investigation is implemented in Fabtech (Textile division) Sangola and results of investigation are interpreted.

A. *Implementation of Wireless Sensor Network at Blower Section of Fabtech (Textile Division) Industries Sangola:*

As discussed earlier, the Textile division of Fabtech industry has four sections such as Blower section, Preparatory section, Spinning section Ring Conner section etc. Out of these four sections, in the beginning the WSN under investigation is deployed in the Blower

Figure 8 : Photograph of Blower section of the Fabtech industry (Textile division)

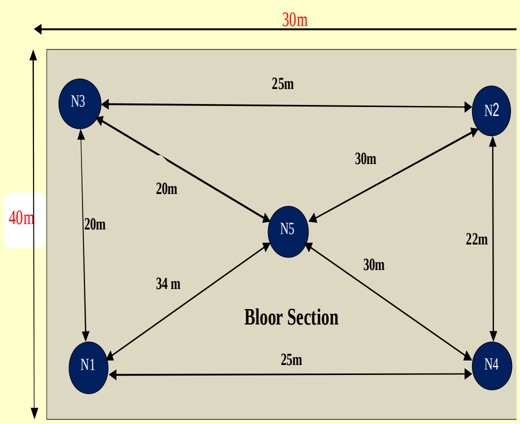

Figure 9 : Schematic of arrangement of the Sensor Nodes in the Blower section

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section. To view at glance, the Blower section is presented in figure 8. In fact, this section has wide area. The five sensor nodes of the WSN under investigation are deployed and results of investigation are presented in this article.

The WSN is established in the Blower section of the industry. The schematic arrangement of the sensor nodes is presented in figure 9. As shown in figure 9, the nodes are systematically deployed to cover maximum area of the Blower section. The distance between sensor nodes and based station is also considered. The distance between sensor nodes and based station is depicted in table 2. For present investigation, two environmental parameters such as environmental temperature (^{0}C) and relative Humidity (%RH) are emphasized.

Table 2: Distance of Nodes placed in the Blower section from Base station.

Sr. No.	Sensor Node	Distance from Base Station (m)
1	Node 1	30
2	Node 2	48
3	Node 3	51
4	Node 4	42
5	Node 5	36

Figure 10 : The Base Station of the WSN for Blower section

The Base station established for present investigation is shown in figure 10. Location of the Base Station is kept same for entire experiment. Actual experimental arrangement of the sensor nodes in the Blower section, which ensures the Site Specific Data Management, is presented in the figure 11. The Sensor nodes collect the information regarding relative humidity and temperature of the region under investigation. After processing at node level, the data is packetized according to the MAC and disseminated toward Base station in star topology. The data given by the sensor nodes are demonstrated on the GUI of the base station and stored in the data base for further investigation.

The WSN under investigation is deployed in the Blower section of the textile industry. Experimental arrangement is shown in figure 10 and 11. The Blower section realizes the cleaning of the cotton using air pressure. The each Sensor Node of the WSN are collecting information regarding environmental temperature and relative humidity of the region where it has been deployed. In fact, the textile division is also having digital thermometers and Humidity meters. These meters are installed at typical location only and not spread into the entire area of textile industry. Therefore, these meters are showing parameter values at respective local point only and do not cover entire area of textile division. Moreover, these meters are not networked. Therefore, the system available in this section does not reveals the central monitoring and control as well. Also, the data logging facilities are not available in this system. Therefore, the WSN under investigation plays remarkable job of data collection and monitoring. Moreover, it is known that both temperature and humidity are the parameters of site specific variability. It also depicts the spatio temporal variation. Values of these parameters specified by the Fabtech industry to maintain the quality of cotton are 32^{0}C and 55 RH%, respectively for temperature and humidity.

The Wireless Sensor Network (WSN) under investigation is implemented for monitoring of temperature and humidity of the indoor environment of the Blower section textile division. The instantaneous values of these parameters are recorded and stored into the database of the Base station and interpreted in this section. In fact, experiment of deployment of WSN for monitoring of the parameter is carried for 10 days and for different periods of the day. However, the data regarding these parameters for typical duration is presented in this section.

B. Monitoring of Relative Humidity (RH%) of Blower section

The values of relative humidity (RH%) sensed by various sensor nodes and collected at the Base Station are plotted against time in Minute. The graph of humidity against time is depicted in figure 12. On inspection of Figure 12, it is found that, an average relative humidity is about 55 RH% as expected. Values shown by the system under investigation and that of obtained from standard system installed by the industry are found close match. This supports the reliability of the WSN under investigation. From figure 12, it is also found that, the humidity within the area of investigation is not uniform. The values depict site specific variability. The values also show time dependence. The values of the humidity varies within 50 % RH to 60%RH. On the inspection of the figure 12, it is observed that, the relative humidity of the area of Sensor Node1 ranges 53%RH to 56%RH. The Sensor Node 2 shows the humidity value within the range from 51%RH to 55%RH. The sensor Node-3 and 4 show the humidity values are in range from 56%RH to 58%RH. However, sensor node-5 shows the humidity values in range from 51%RH to 59%RH respectively. The WSN under investigation precisely depicts the site specific variability in the indoor parameter values.

C. Monitoring of Environmental Temperature (^{0}C) of Blower section

Instantaneous values of environmental temperature in ^{0}C are recorded against time in minutes. The data is also stored in the data base of the Base station and used for further presentation. The values of Environmental Temperature (^{0}C) sensed by various sensor nodes and collected at the Base Station are plotted against time in Minute. The graph of temperature against time is depicted in figure 13.
On the inspection of the figure 13, it s observed that, Sensor Node1 shows the temperature values in the range of 29^{0}C to 32^{0}C and

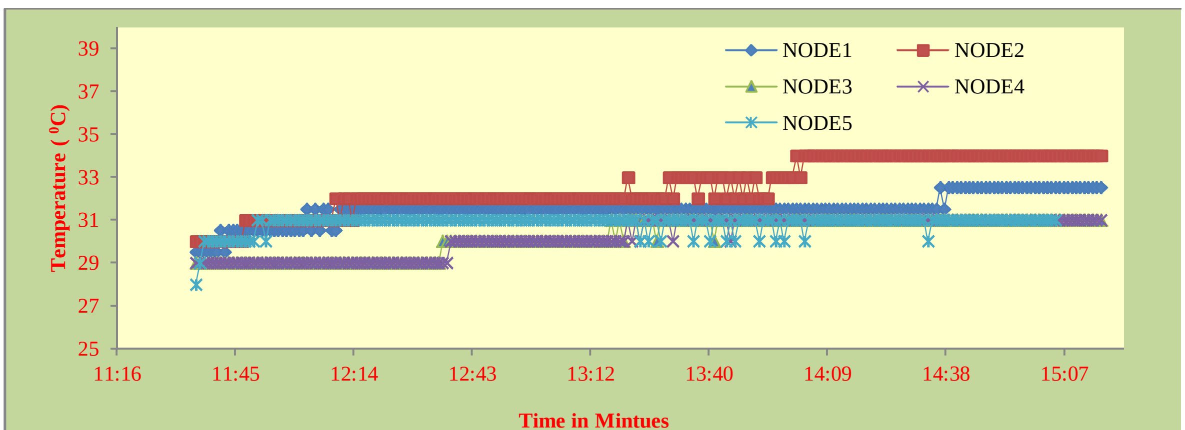

Figure 13 : Instantaneous values of environmental temperature in (^{0}C) measured in an environment of the Blower section of the textile division of the Fabtech industry.

Thus, from results of this investigation, it can be said that the wireless sensor network under investigation is most reliable and precise.

V. CONCLUSIONS

The wireless sensor network of five sensor nodes and the coordinator node is successfully established and deployed for monitoring of industrial environmental parameters such as indoor relative humidity, indoor environmental temperature of the blower unit of textile industry. For realization of on-site implementation, the industries such as fabtech industry (Textile Division), milk processing industry and alcohol manufacturing plant of sugar industry are selected. The WSN under investigation is deployed for monitoring of above parameters. Under the frame of IEEE 802.15.4, the WSN is successfully implemented in star topology. The WSN parameters such as RSSI, LQI etc have been investigated. Values of these parameters are in the limit of zigbee communication. On investigation of instantaneous values of various parameters, it can be concluded that the environmental parameters depict site specific variability with spatio-temporal variations. The multi-hopping techniques also successfully implemented to ensure monitoring of wide area of typical industry.
On investigation of the results of on-site deployment of WSN under investigation, it can be concluded that, the WSN under

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investigation is operating with great reliability and preciseness.

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