Volume 5, Issue 12, December 2015 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Design and Deployment of ARM Microcontroller Based Wireless Sensor Network to Monitor Industrial Parameters

S. V. Chavan*, S. K. Tilekar, B. P. Ladgaonkar
VLSI Design and Research Centre, Post Graduate Department of Electronics,
Shankarrao Mohite Mahavidyalaya, Akluj, India

***Abstract-** Indeed, Wireless Sensor Network (WSN) is an emerging field, exhibiting interdisciplinary relevance. In industry, monitoring of the physical parameters such as temperature, leakages of ammonia (NH_3) gas and weight of the finished product etc is essential. In fact, these parameters depict spacio-temporal variance. To play with such site specific data, deployment of the WSN is most suitable solution. To monitor such parameters the wireless sensor network is established, wherein the wireless sensor nodes play a major 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 three parameters such as, environmental temperature (^0C), leakage of ammonia (NH_3) gas (%) and Weight of the finished product (gm) etc. The smart sensors, LM35 for temperature, FC-22-I noxious gas sensor module for ammonia measurement and load cell for weight 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 dairy industry. The results of design and implementation of WSN for monitoring of industrial parameters are interpreted in present paper.*

***Keywords-** Wireless Sensor Networks, Zigbee RF Module, ARM Microcontroller, GUI, Base Station.*

I. INTRODUCTION

Wireless sensor network (WSN) is an innovative technology and it has been proved its suitability for various sectors. It depicts an enormous potential for industrial and commercial applications [1-3]. The wireless sensor network is the establishment of systematically distributed sensor nodes, who have the capabilities of sensing as well as computation [4]. The nodes are autonomous and sense the information about various parameters typical of grid of defined area [5]. Each node solders the responsibility of its own grid. Therefore, the nodes interact with the physical world and collect site specific information at the base station [6]. Thus, the WSN is most suitable for collection of information spread over wide area. On intensive study, it is found that, the WSN is significantly used for precision agriculture [7], wherein, the parameters of spatio-temporal variations should be essentially monitored. The WSN also proved its suitability for monitoring transportation, environmental monitoring, forecasting, pollution monitoring, security, disaster management etc [8]. Moreover, it is most suitable for monitoring of industrial parameters. In industry various physic-chemical parameters are to be monitored. For monitoring of such parameters, at present, wired networks have been deployed by many industries. However, use of wired network has its own constraint due to hardware complexity and ultra high power consumption. Therefore, the paradigm shift from wired to wireless networking is realizing. Therefore, for monitoring of industrial parameters, the WSN can play commendable role.

In case of industry, various physico-chemical parameters such as temperature, pressure, humidity of environment, leakages of various gases, water quality, pollution due to industrial waste, pH of solution etc have to be monitored by sophisticated electronic system, wherein the centralized monitoring is emphasize. The wireless sensor network is most suitable technology to cater this need. Out of the above parameters, the temperature of the environment, concentration of hydrogen sulfide gas and ammonia gas in the industrial air and the pressure at typical industrial process etc parameters are considered for present investigation. These parameters can be collected through the network of sensor nodes, wirelessly connected to each other and to the base station as well. According to standard architecture the node has a processing unit, memory unit, RF transceiver module, power source and an array of sensors as well. The sensor node communicates wirelessly and self organize after being deployed in an ad hoc network. The WSN realizes the deployment of IEEE 802.15.4[9, 10] standards of wireless communication. The Zigbee technology is playing major role in establishment of wireless sensor network for dedicated applications [11, 12]. It is anticipated that, within few years the world may be linked with wireless sensor network and provides accession with the internet, to realize the concept of Internet of Things (IOT) [13, 43]. To address the theme of IOT, the density of the nodes should be significantly more. Therefore, exact and low power sensor nodes are necessary for the development of wireless sensor network. In facts, the nodes can be designed with microcontrollers of promising features. The features of the sensor nodes vary with the designing issues of hardware and software. Therefore, designing of the nodes of prominent features is one of the challenging tasks. It is known that, the microcontrollers from ARM Cortex family show prominent features, which are highly suitable for embedded development. Moreover, the wireless sensor node realizes the design of embedded system. Therefore, deploying ARM Cortex M4 microcontroller, the nodes have been designed to monitor the industrial parameters and results are interpreted in this paper.

II. REVIEW OF THE LITERATURE

Indeed, due to revolutionary development, the WSN find wide spectrum of application in diverse field. Therefore, the researchers are showing interest in design and implementation of wireless sensor network technology to the industrial applications. Emphasizing the deployment for the atomization of the industrial processes, the wireless sensor network has been demonstrated by Flammini et al [14], wherein the facet of real-time Ethernet protocols have been implemented to monitors the parameters of the industrial processes. Shen et al [15] have developed wireless sensor network for industrial application. They intensively studied various protocols and comparative results are interpreted. Zhao reviewed the development of WSN and its application for industrial sectors [16]. He intensively studied various WSN and reported the challenging issues of designing and acceptance of WSN for process automation. He also compared the WSN of various vendors and reported their merits and limitations. He concluded that, further research is necessary to enhance the reliability, accuracy, responsiveness, smart routing powers saving etc related issues. He highlighted that, the deployment of WSN within feedback control systems raises lots of problems and challenges. The WSN is implemented by Low [17] for process controlling. He reported commercial WSN platform for industrial applications. Erdelj et al [18] have reported various issues of WSN required for industrial application. Keeping pace with the industrial needs, they reported the new network called Industrial Wireless Sensor Network (IWSN). Paavola and Leiviska [19] have developed the wireless sensor network for industrial automation. Emphasizing the industrial sector, they focused the standards ISA 100, for wireless communication, for development of the WSN. They also reported the various factors, who exhibit interferences inthe process of data communication from node to node and from node to base station as well. The interferences due to walls, machines and multipath propagation also adversely affect on the performance of the industrial WSN.

In addition to industrial WSN, many researchers are reported the results of implementation of WSN to agriculture. Lee et al [20] have designed the paprika greenhouse system (PGHS), which collects the paprika growth information along with greenhouse information to control the paprika growth. The system provides with the growth environment monitoring system, which is monitoring the paprika growth, wherein they measured the temperature, light intensity, leaf wetness and fruit conditions. They installed the system to improve the growth of the paprika and analyzed the collected information. The Hasstriyandri [21] have designed the multisensory system for monitoring the temperature of greenhouse. The multiple sensors have been placed in a greenhouse in systematic manner to measure the temperature of greenhouse. The system allows more comprehensive observation for conducting an analysis of the temperature using wireless communication. The wireless sensor network was designed by Xiaojuanet. al [22] for H_2S gas monitoring at the oil processing plant. In the presented system, the toxic gas is detected during oil exploration & refinery and demonstrated the protocols to establish the fully functional network. Moreover, they also provided comprehensive energy model to evaluate the feasibility of employing wireless sensor network for the monitoring task. The sensing technology has been widely investigated and used for gas detection. A flexible and reliable gas detection system, to detect the gases such as combustible and LPG in the real time is developed by Hema et al [23]. The designed system content the microcontroller 16F877A as a computational unit and for data communication the GSM technology is employed. The online measurement of weight of the raw material as well as finished product is inherent process in the industry. Therefore, the many researchers have been working on the field of on-line measurement of weight and force with advanced technology. The Pimhataivoot et al [24] have discussed the compression force measuring system for rotary tablet pressures. The compression force has become more important in quality control of tablet compression. In presented system load cell from HBM is employed at the compression rollers eyebolt. The bridge amplifier, analog to digital converter and microcontroller from TSM is used to compute the average maximum compression force and hence weight of the tablets. Similarly, Sirithunyalug et.al [25] also discussed the system of punch displacement instrumentation for tablet machine for pharmaceutical industry. Thus from literature survey, it can be said that, the WSN is widely deployable for atomization in the industry. Therefore, many people are undertaking the research work on development of WSN for monitoring of industrial parameters. In this paper, results of design and implementation of nodes for monitoring of industrial parameters are interpreted.

III. DESIGNING OF WIRELESS SENSOR NODE

Following the basic architecture, the wireless sensor node is designed for industrial application for monitoring dedicated parameters. The LM4F120H5QR ARM microcontroller is used to develop the computing unit. Figure 1 shows the block diagram of hardware of the wireless sensor node. To realize the wireless communication the zigbee technology is deployed. Present system is designed about the RF transceiver Xbee series-2 from DIGI International Inc. The PHY and MAC layers of zigbee stack [26], as per IEEE standards are deployed. However, it is attempted to reconfigure the application and network layers. According to the block diagram depicted in figure 1, the signal conditioning circuits have been designed for each sensor.

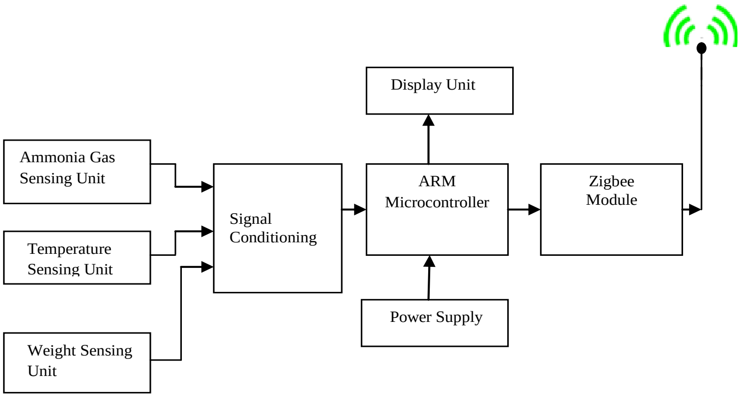

Figure.1 Block Diagram of Wireless Sensor Node (END Device)

The nodes are developed for monitoring of environmental temperature, leakage of ammonia gas and weight of the product. Each of the nodes is configured as End device, which allows to physically interacting with the measured. Along with the nodes the co-ordinator is also designed and interfaced to the base station. All nodes and the co-ordinator are configured by using X-CTU IDE provided by Digi Corporation. Present communication emphasizes the design of sensor nodes for WSN for monitoring of typical industrial parameters. Moreover, employing these nodes the WSN is also established at typical industry and results of implementation are also discussed.The design issues are presented in this paper through following sections.

A) Hardware of Wireless Sensor Node.
B) Firmware for Wireless Sensor Node.
C) Designing of smart Base Station.

3. A. Hardware of Wireless Sensor Node.

Architecture of the sensor node is depicted in figure 1, moreover the circuit schematic is presented in the figure 2. It is known that, the wireless sensor node is the realization of embedded system design, wherein both hardware as well as software should be co-designed.

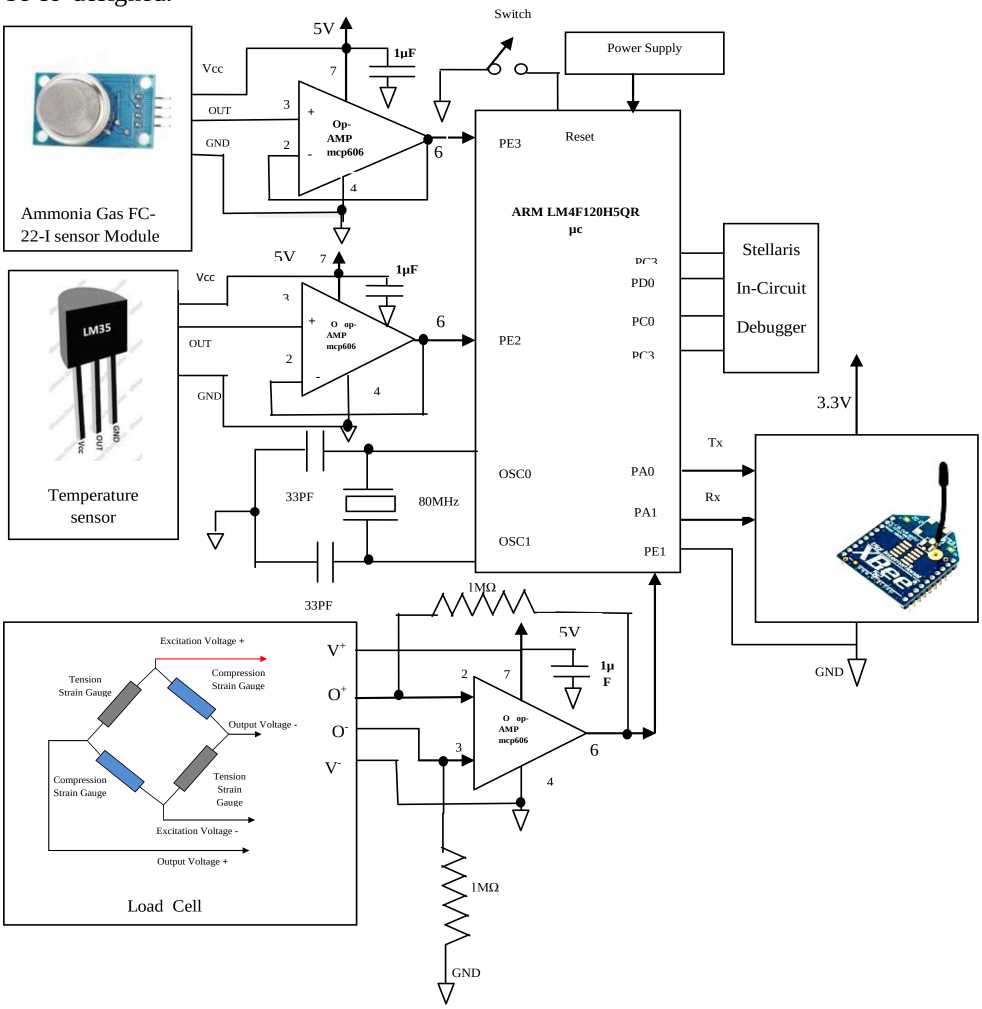

Figure.2 Schematics of the Wireless Sensor Node designed for monitoring of environmental temperature, leakage of ammonia gas and the weight of the product.

As shown in figure 2, the wireless sensor node consists of the blocks such as an array of smart sensors, signal conditioning circuit, ARM microcontroller, display unit, power supply, RF module Xbee series-2 module etc. The system is designed to monitor typical industrial parameters such as environmental temperature, Ammonia gas (NH_3) and weight of the product.The wireless sensor node consits of an array of sensors such as temperature sensor LM-35, ammonia gas sensor module FC-22-I and load cell for weight measurement. These sensors are highly reliable and produce D.C emf, which is directly proportional to the actual values of respective parameters. An electrical signal produce by the sensors are conditioned. The signal conditioning circuit is wired about CMOS operational amplifier MCP606. On chip ADC of the ARM microcontroller, LM4F120H5QR [42],is employed for data conversion. The RF module Xbee series-2transceiver is facilitated with UART interface. Therefore, it is interfaced with microcontroller at UART port. The RF module is configured to support IEEE 802.15.4 standards. The analog as well as digital part of present embedded system is designed and the designing issues are discussed subsequently through following points.

3.A.1 Arrays of Sensors

The system under investigation realizes the design of wireless sensor node for monitoring of industrial parameters, the temperature, ammonia gas and weight of the product in particular. For this purpose the deployment of sensors of promising feature is necessary. Therefore, as discussed earlier the sensor modules LM-35, FC-22-I Noxious gas sensor and load cell are deployed as sensors. The details regarding these sensors are highlighted through following sub sections.

3.A.1.(a)Temperature Sensor (LM-35):

The temperature is the one of the most important parameter in industrial process. Precision measurement of temperature is essential for variety of industries such as agro industry, food industry, food storage houses, sugar-cane factories; automobile industry etc. The temperature of the process and environmental temperature are two different measured. Present system is designed for measurement of environmental temperature. The present wireless sensor network is implemented for monitoring temperature in the milk processing factory environment. Therefore, system is deployed to monitor the temperature of milk tanks and other sites of investigation. The LM-35 series is of precision integrated circuit temperature sensors, whose output voltage is linearly proportional to the temperature in degree Celsius. On investigation of its structural details, it is found that the LM-35 sensor is most suitable sensor for present. The LM-35exhibits typical accuracies of +/-0.25^oC at room temperature and+/- 0.75^oC over a full -55^0C to +150^oC temperature range. The current consumption is less than 60µA [27]. The change in emf produced by the sensor is extracted and given to further processing. The temperature coefficient (α) exhibited by this sensor is 10 mV/^0C. Considering these facts the signal conditioning circuit is designed.

3.A.1.(b)Ammonia gas Sensor(FC-22-I):

Existence of ammonia gas (NH_3), in industrial environment may cause some catastrophe. To avoid such accidents the detection of ammonia gas leakage is important. For real-time, monitoring of ammonia gas leakages, the wireless sensor network is developed. In the present research work, the WSN is implemented at food industry, particularly for milk dairy, wherein, the ammonia gas is employed for refrigeration. Therefore, to maintain the quality of the milk based product, the plant must be protected from ammonia gas leakage. Moreover, the temperature should be essentially maintained at the precise level.

Indeed, ammonia gas is an important chemical material; it is widely used in industrial production. However, if the concentration of the ammonia gas is increased in the atmosphere it may cause the accident. Ammonia leakage or heavy concentration of ammonia in air is responsible for poisoning of the environment, easy combustion and explosion. Therefore, ammonia gases seriously affect human health and security. Therefore, wireless sensor network is established for monitoring of leakage of ammonia gas. The FC-22-I Noxious gas MQ-135 gas sensor module is used to detect the ammonia gas. The figure 3 shows the photograph of FC-22-I Noxious gas sensor module, wherein the MQ-135 ammonia gas (NH_3) sensor is deployed [28]. The conductivity of the ammonia gas sensor material rises along with the concentration of the ammonia gas present at that time in a chilled storage room. The sensor module FC-22-I has ability to detect various harmful gases such as hydrogen Sulfide, Nitrogen oxides, Benzene steam, Smoke etc also. However, its sensitivity to the ammonia gas is significantly high than that of for other gases. The lower cost and high performance of FC-22-I sensor module makes an ideal choice for the measurement of ammonia gas.

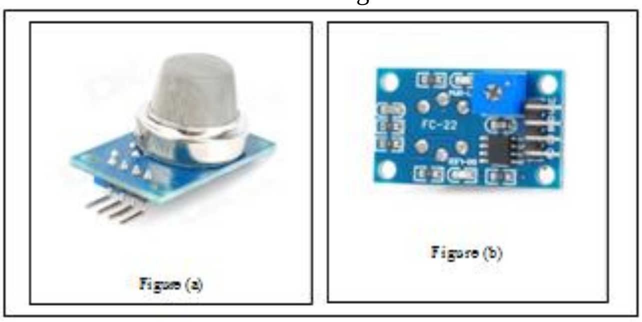

Figure 3 a) Front side of FC-22-I ammonias gas sensor module and b) the back side of FC-22-I sensor module

The sensor module has four pins; pin -1 is a power supply for sensor module (Vcc), pin-2 provides an digital output voltage (DOUT) in TTL levels, pin-3 provides an analog output (AOUT) voltage, pin-4 is for ground (GND). The typical features of FC-22-I sensor modules are given in [28].

3.A.1.(c)Weight Measurement (Load cell):

Measurement of weight is a important and essential job in many industries. Accurate and online measurement of weight is a challenging task. Therefore, for the present work, the new system is designed, which is capable of measuring weight and disseminating the measured weight to the base station for online monitoring. The advanced technology wireless sensor network is employed for accurate and online measurement of weight. In the wireless sensor network, sensor nodes equipped with a load cell sensor (ET2000) for monitoring of weight of the finished product. The Load cell (ET2000) is employed to convert a force into electrical signal (emf).

In present system, to monitor the weight of the product, the load cell is employed, which has four strain gauges wired in a Wheatstone bridge configuration. This load cell, due to deformation, produces emf proportional to the weight of the product. The strain gauge measures the deformation as DC emf. The present system is employed in Milk Dairy industry wherein, weight of the milk packets should be online monitored. To monitor the weight of packet the system is designed and calibrated.

On the inspection of process of the milk dairy, it is found that measurement of weight ofthe milk bags is essential, before put into market. Presently, the weight of milk bag is measured using weighing machine. The packetizing machine fills the bags with determined quantity of milk. In fact, the milk packed into the bag, by the machine is in the unit of volume of milk such as ¼ liter, 1/2 liter and 1-liter etc. Upon filling, the bags get sealed and conveyed out. The machine is fully automatic. However, to ensure quality as well as quantity control, the weight of bag is frequently checked by traditional method, wherein in the traditional weighing machine is used. Moreover, the weighing machine is kept at the controlling laboratory, located sufficiently away from the milk filling plant. In this method, the weights of all bags are not checked. Usually, a sample of bag, approximately after 100 bags is considered for verification of the weight. This method is unreliable. Therefore, on line measurement of weight of milk bag is proposed to ensure preciseness in quantity control. Employing the density of whole 1.026 of the typical milk [41], the weight of 500ml bag should be 513gm. If the weight of the milk packet deviates from 513gm, then the quantity of the milk may be deviated from 500ml. If this happens, then the operator inhibits the filling process and rectifies the problem and after successful implementation of the solution, the packetizing machine re-assumes the milk filling process. This is tedious process and mostly depends upon the operator's skill. This also provides the impediment to the process of full atomization. To ensure the process of atomization, online measurement of the weight and demonstration and collection of this information, in real time, at monitoring cabin is essential. In fact, the operator is not aware about the nature of electrical signal and data conversion as well. Therefore, signal conversion into digital form and for further processing ARM LM4F120H5QR microcontroller is used.

3.A.2 Signal Conditioning:

As discussed earlier, all three sensors are providing dc emf, which reveal linearity with respect to the variation in the parameters values. To realize the need of measuring instrumentation, the signal conditioning is in envitable. The signals under investigation are interfaced to the operational amplifiers, wired as signal conditioner. As depicted in figure 2, the signal conditioning circuit is wired about CMOS operational amplifier MCP606, which exhibits rail to rail characteristics for both input and output purpose. It suitably provides sinking and sourcing current at precise level. It exhibits ultra high input impedance and very low input offset voltages. The CMOS operational amplifier is configured as a buffer which helps to ensure isolation of the sensors. The features of this family of operational amplifier are well suited for single supply precision, high impedance and battery powered applications [29], which are essential features of the wireless sensor nodes. The signals are conditioned and then subjected to further process of digitization and calibration.

3.A.3 Computing Unit

On extensive study of architecture of wireless sensor node, it is realized that the sensor comprises a computing unit with promising features. Essentially, limited computing capability is the key feature of node. A computing unit of present node is designed about LM4F120H5QR microcontroller. The Data Acquisition System (DAS) is most important part of measurement instrumentation. In fact, DAS consists of devices such as analog multiplexer, demultiplexer, FIFO register, ADC, processing unit etc. Now days the embedded processor are coming with advanced features [30]. Microcontrollers from ARM families are becoming more and more pervasive, because of their commendable features. Deploying LPC2148 series the designing of an embedded system for dedicated application is reported by various investigators [31,32, and 33]. In addition to the LPC series, other ARM families also show advanced on-chip resources [34, 35]. Deploying LPC2378, Kumar et al have demonstrated the design of smart sensor module for monitoring of industrial temperature and he also controlled the temperature of the industrial environment [36]. These controllers have the cores such as ARM7, ARM9 etc with TDMI facilities. Recently, due to introduction of cortex philosophy, the ARM cores have become smarter [37]. Microcontrollers with this core also support the analog computation. The ARM microcontroller LM4F120H5QR is having promising on-chip features. It`s architecture is developed about ARM Cortex-M4 processing core. It proved its suitability for analog computation as well. An analog to digital converter should be essentially deployed in measurement instrumentation, which converts a continuous time domain analog signals. The Texas Instruments Stellaris family based ARM LM4F120H5QR has two analog to digital converter (ADC) such as ADC0 and ADC1. Its ADC modules are featured with 12-bit resolution and supports 12 – input channels. Availability of such smart on-chip data converters reveals, mixed signal kind of philosophy [38]. Each ADC module contains four programmable sequencers allowing the sampling of multiple analog input sources without controller intervention. The trigger source for ADC0 and ADC1 can be configured independently. Moreover, two ADC modules may be operated from the same trigger source and on the same or different inputs. The sampling control and data capture is handled by on chip sample sequencers. All of the sequencers are identical in implementation. In present design, the sample sequencer '0' (SS0) is employed. It is also found that, the register of FIFO type is associated with the sample sequencer. The sample sequencer is capturing 4-samples and allowed to hold in the FIFO register of 4 byte. Present microcontroller exhibits 32-bit processing capacity. Therefore, the FIFO register are also 32-bit word. In present implementation, each FIFO register, out of 32-bit word, the lower 12-bits are containing the conversion result. The sample sequencer '0' (SS0) has 4-FIFO registers. First FIFO register stores ammonia gas related results, which are coming from pin AIN0 (PE3). Moreover, second, FIFO register stores temperature dependant results, which are obtained from pin AIN1 (PE2), the third, FIFO register stores weight of sample, which are obtained from pin AIN2 (PE1). Each sample is defined by the bit fields in the ADC Sample Sequence Input Multiplexer Select (ADCSSMUXn) and ADCSample Sequence Control (ADCSSCTLn)registers. The ADCSSMUXn fields select the input pin, while the ADCSSCTLn field selects the sample control bits corresponding to parameters. Sample sequencer are enabled by setting the respective ASENn bit in the ADC Active Sample Sequencer (ADCACTSS) register and it should be configured before being enabled. Sampling is then initiated by setting the SSn bit in the ADC Processor Sample Sequencer Initiate (ADCPSSI) Register. After a sample sequencer completes execution, the conversion result can be popped up from the ADC Sample Sequence Result FIFO (ADCSSFIFOn) registers. The ADC0 uses the internal reference voltage 3.3V. Most of the ADC logic runs at the ADC clock rate of 16 MHz. On chip prescalar are configured for 16 MHz operation. ADC modules interrupt signal are controlled by the state of the MASK bits in the ADC Internal Mask (ADCIM) register. Interrupt Status can be viewed in the ADC Interrupt Status and Clear (ADCISC) register, which show active interrupts that are enabled by the ADCIM register. Thus, the data converters are configured to ensure analog to digital conversion. The digitized data is used for further computation. A firmware id developed and ported into the target flash and used to synchronize above operations. Thus, the computing unit of present sensor node is designed and deployed to ensure autonomous operation of the wireless sensor nodes.

3.A.4 RF Module (Xbee Series - 2):

To realize the design of wireless sensor node, along with sensing and processing unit, the RF communication unit is equally important. It is known that, a variety of RF modules are available to ensure wireless data communication. For present nodes the Xbee series-2 RF module are employed. The Xbee transceiver RF module from DIGI international Inc, is operated according to Zigbee IEEE 802.15.4 standards, within the 2.4 GHz unlicensed ISM band. This chip enables industrial grade applications, at low voltage operation. In addition, Xbee provides extensive hardware support for frame handling, data buffering, burst transmission, data encryption, data authentication, clear channel assessment etc. The features of RF module Xbee transceiver have given in [39].

According to architecture of this RF module, it is a 20 pin RF module and it provides UART interface [39]. The minimum pin required to interface with UART are VCC, GND, Rx and Tx. As discussed earlier, an analog and digital section of present node produces the data related to respective parameter values. It is then given to the RF module Xbee series-2 for transmission. The Xbee series-2 RF module receives the parameter values from microcontroller. The Xbee series-2 uses IEEE 802.15.4 standard packet format for transmitting the data.

3.B. Firmware for Wireless Sensor Node

The software employed in sensor node (END Device) developed by using Code Composer Studio (CCS) Version IDE in embedded 'C' environment. In this IDE various software modules are developed for monitoring the industrial parameters. In the beginning, the RF Xbee module is initialized and allowed to search the network. It operates in polling mode. On availability of the network, immediate it joins the network. Now, the RF Xbee module is linked into the network. Meanwhile, the processing unit, ARM microcontroller, provides the digital data proportional to the parameter values. An empirical expression obtained from the process of calibration are deployed in the firmware on continues execution of these expressions the computing unit produces the values of the parameters, under investigation, in real units. Serial communication module initializes the UART module and then transmits the data in specific word format towards the coordinator node. Thus, the wireless sensor nodes are designed for realization of wireless sensor network.

3.C. Base Station (BS):

According to structural design of the WSN, the base station is equally important. It comprises co-ordinator node and the desktop. It is essential for demonstration and storing of the data in specific format of the data.

3. C. (i) Designing of Base Station:

The schematic of the base station is depicted in figure 4. As shown in figure 4, the base station comprises the co-ordinator node and computer for demonstration of data.

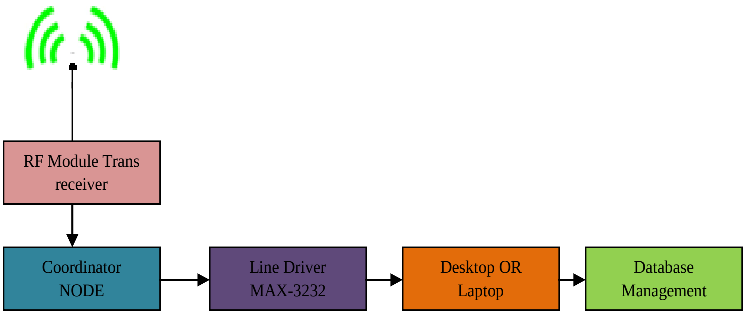

Figure.4 Block Diagram of Base Station with Coordinator

The co-ordinator node is also designed about ARM LM4F120H5QR microcontroller and the design is almost identical with that of end device. Therefore, the discussion on designing issues of the hardware of the co-ordinator node is similar to that of sensor node. Moreover, any sensor node can also be configured as the co-ordinator. Moreover, embedded firmware is also designed and ported into the target device. As shown in figure 4, the co-ordinator is connected to computer system through serial interfaced. An UART is used to ensure interfacing of co-ordinator to the computers. The coordinator is interfaced with to computer system through the line driver MAX3232. 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.

3.C.(ii) Graphical User Interface for Base Station (BS):

The Graphical User Interface (GUI) is designed in Visual Basic (VB 6.0), environment to facilitate the base station (BS) of wireless sensor network (WSN).

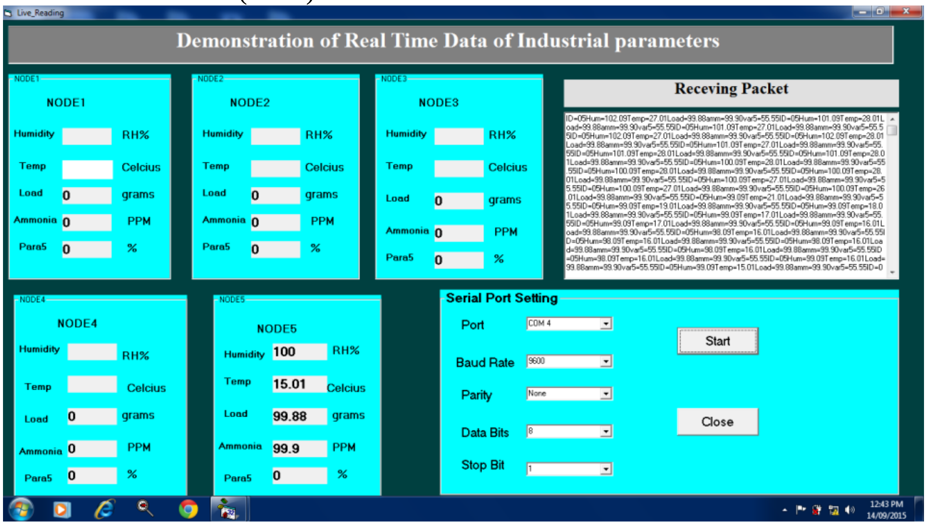

Figure.5 Snapshot of VB Based GUI for Live Monitoring

The wireless sensor network incorporates the Base Station (BS) to monitor the distributed data regarding industrial parameters. As per the structural design of the wireless sensor network (WSN), the nodes have been designed and routed by ensuring Zigbee technology. The node collects and disseminates the site specific data towards the base station. Moreover, the present design is devoted for measurement of industrial parameters. Therefore, the parameters values should be demonstrated in user's friendly format. The graphical demonstration of data is always suitable [40]. To facilitate the graphical presentation of data, the design of GUI is needed. To facilitate the fundamental needs of the base station, smart Graphical User Interface (GUI) shown in figure 5 is designed and implemented. The coordinator node is interfaced to the serial port of the computer. Immediately, the GUI act upon the serial port and read data from serial port. The data is in typical frame. Therefore, the GUI disassembles the packet and isolates the environment parameter values along with respective headers and identifiers. The parameter values, temperature, concentration of ammonia gas and weight of the milk product are extracted and displayed into respective windows. The windows are continuously updated with the recent data. Typically, for present WSN, 5 nodes are routed. Therefore, 5 windows are created to display parameter values of respective nodes. Moreover, instantaneous values of the parameters are also stored, in real time, into the database created for this dedicated purpose.

IV. CALIBRATION OF THE SENSOR NODE

As discussed earlier, the wireless sensor nodes have been designed by co-developing of both hardware and firmware. Moreover, present nodes have been designed to monitor the parameters of site specific relevance. The calibration of the device is the facet of the measurement instrumentation. Therefore, before implementation, the nodes are calibrated to the respective scientific unit. The nodes have been designed to monitor environmental temperature, concentration of ammonia gas leaked into the air and the weight of milk packets. Therefore, the nodes have been calibrated to the respective units and methods adopted for the calibration are discussed through subsequent points.

4.A. Calibration of the Node to the Temperature in Degree Celsius:

It is known that, the sensor unit comprises LM 35 as a temperature sensor. It is semiconductor, monolithic sensor and provides an output emf (V_t) directly proportional to the environment temperature, in degree Celsius. The temperature coefficient is ($\square_{t)}$ is 10mV/^{0}C. Therefore, emf values shown by the system under investigation are recorded against various temperatures from 25^{0}C to 100^{0}C. The graph, of observed emf (V_t) plotted against temperature in ^{0}C, is shown in figure 6. The graph depicts linear variation. On implementation of regression process, an empirical relation, equation 1, is obtained.

$$V_t = 10\, t \qquad \ldots(1)$$

On inspection of equation 1, it is found that, the emf shown by analog section of the node has temperature coefficient of 10mV/^{0}C. This may be due to temperature coefficient of the sensor. Therefore, the equation 2, Temperature (t) = V_t / 10 …(2)

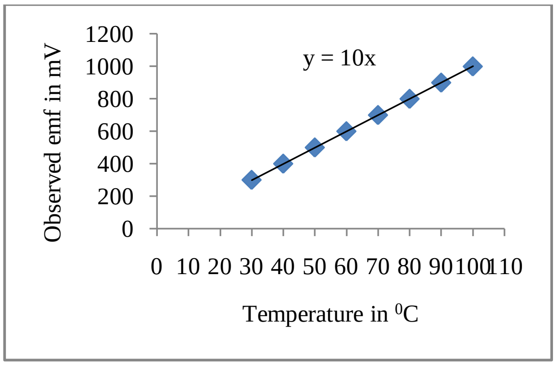

Figure.6 Graph of observed emfV_t (mV) against applied temperature t (^{0}C)

Table.1 Temperature Shown by the System under Investigation and Standard Thermometer.

Temperature (^{0}C) Shown By	
Standard Thermometer	System under investigation
30	30.0
35	35.0
40	40.0
45	45.0
50	50.0
55	55.0
60	59.0
65	63.5
70	68.2
75	71.9
80	83.2
85	84.3
90	86.8

is employed in the firmware, 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 1. The close match of the temperature values supports the reliability of hardware and software design.

4.B. Calibration of the Node to the Concentration of Ammonia Gas (NH_3) in Percentage:

It is known that, sensor module comprises MQ-135 ammonia gas sensor. It consists of resistive type sensing element of SnO_2. The sensor module has on-board signal conditioning and provides an output emf (V_A) directly proportional to the concentration of ammonia gas. Therefore, emf values shown by the system under investigation are recorded for two extreme values of ammonia gas. The emf is measured at ambient condition and secondly, it is measured on exposing the sensor module to environment with the saturated ammonia gas. Therefore, at ambient condition, the ammonia is supposed to be zero percentage, whereas at saturated environment, an environment of the ammonia gas cylinder, the concentration is supposed to be 100%. The graph of observed emf (V_A) plotted against concentration of gas (C_A) is shown in figure 7. On implementation of regression process, an empirical relation, equation 3 is obtained.

$$V_A = 11\ C_A + 100 \qquad \ldots(3)$$

The ammonia gas (NH_3) dependant voltage (V_A) is recorded in mV. Therefore, the slope of the graph,α_A= 11, represents ammonia gas coefficient of the system under investigation. Equation 3, also reveals the offset of emf about 100mV. According to datasheet of ammonia sensor, being resistive type, it shows typical resistance value at ambient condition. Due to this resistance, upon biasing, an emf of about 100mV is produced. This offset voltage is compensated by the execution of equation 4.

$$C_A = [(V_A - 100) / 11] \qquad \ldots (4)$$

This equation employed in the firmware, which executes to produce continuous values of ammonia concentration in percentage unit.

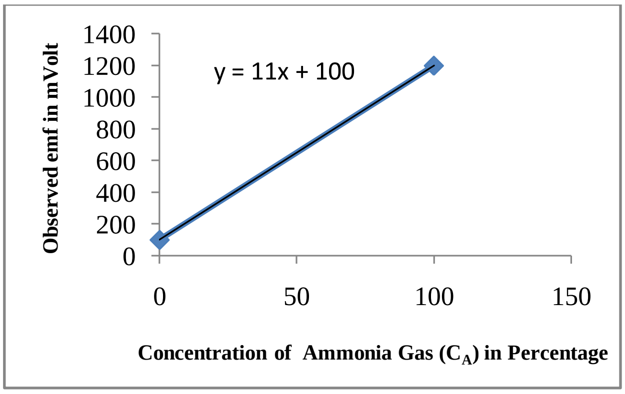

Figure. 7 Graph of observed emf V_A (mV) against Concentration of Ammonia Gas (%)

4.C Calibration of the Node to the Weight measurement in Grams:

For the measurement of weight of milk packet, the load cell is employed as a sensor. The load cell provides an output emf (V_L) directly proportional to the applied mass in grams. Therefore, emf values shown by the system under investigation are recorded against applied mass in grams. The graph of observed emf (V_L) plotted against the applied load in grams, is shown in figure 8. The graphs depict linear variation.

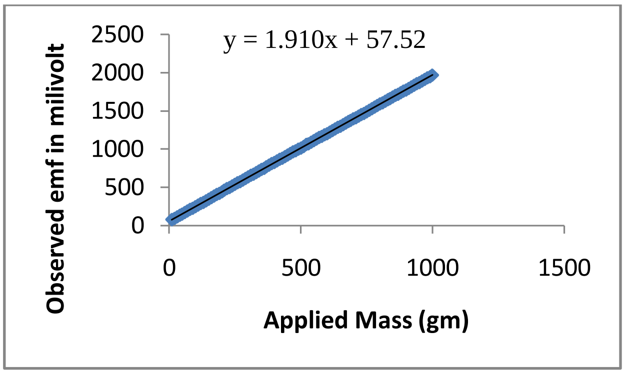

Figure. 8 Graph of observed emf V_L (mV) against applied mass (gm).

The mass dependent voltage (V_L) is recorded in mV. The range of investigation is from 0 gm to 1000 gm. For the precise calibration, the load dependent voltage recorded several times and averaged data is used for the process of regression. Therefore, the empirical relation obtained is given in equation 5.

$$V_L = 1.907m + 64.27 \qquad \ldots (5)$$

Therefore, the slope of the graph, $\alpha_L = 1.907$, represents, the load coefficient of the system under investigation. Equation 5 also reveals the offset of emf about 62.27 mV. This offset may be due to mechanical arrangement and balancing of the load cell. However, this offset gets compensated by employing equation 6 into the firmware.

$$m = [(V_L-64.27)/1.907] \qquad \ldots(6)$$

The equation 6 is employed in the firmware which executes to produce continuous values of weight of packets in grams.

V. IN-SITU ESTABLISHMENT OF WSN:

As discussed in earlier sections, the wireless sensor nodes have been designed and prototype of the typical node is presented in figure. Moreover, it is also calibrated to respective units. Now, these nods are ready for establishment of the network. The five nodes and co-ordinator are used and network is established in star topology, wherein all nodes are sending data towards co-ordinators. In the beginning, to realize the operation of WSN, the nodes were placed systematically, on the play ground and data send by each node is recorded at the base station. Moreover, on-site implementation of WSN for on-line monitoring of dedicated industrial parameters is one of the objectives.

For on-site implementation, a dairy industry of Shivamruth Doodh Udpadak Sangh Ltd Akluj was selected. This dairy plant is realizing high-tech engineering and ensuring atomization in the various processes. However, in this industry the plants are individually controlled and monitoring of distributed parameters together at one control unit is not carried out. Therefore, on implementation of present system at this industry may really helps to demonstrate the salient features and advantages of the wireless sensor network. This dairy is spread over wide area. Each plant is separately controlled. Out of all, the processing plants considered for present deployment are, refrigeration plant, milk packetization section, milk chilling and storing section. Present wireless sensor network is established at these sections and values of the parameters under investigation are recorded at base station. The results of this implementation are discussed through following points.

A. Deployment of WSN at Milk Chilling and Storage Plant
B. Deployment of WSN at the Refrigerator Section
C. Deployment of WSN at Milk Bag Filling Section

5.A. Deployment of WSN at Milk Chilling and Storage Plant

Milk chilling and storage plants of this dairy is referred as Sylo milk chilling and storage plant. The wireless sensor network is established at Sylo Milk-Tank section. This section comprises five milks tanks numbered from Sylo-1 to Sylo-5. In the Sylo tanks, the milk is stored and chilled at very low temperature. The chilling temperature is controlled at 8 to 10^0C.

5.A.1 Experimental Setup:

For the chilling and storage section of the dairy considered for on-site implementation, the chilling temperature is major parameter. This plant is having its own system of monitoring of the temperature only. The temperature is monitored on the display of individual tank. However, the monitoring control mechanism is not employed. Moreover, at present the data is not recorded in real time. The plant operators supervise the status of the tanks and take decision to control the temperature.

At present, this section of dairy is not having any centralized monitoring system. Thus, the monitoring system used in the milk chilling and storage plant exhibit limitations in their precise operation. Therefore, deployment of wireless sensor network at this section may help to realize the modernization in the plant. Therefore, the WSN under investigation is established at this section of the dairy. As shown in the figure 9, the section is spread over the area about 80 ft × 70 ft and tanks are distributed systematically. The wireless sensor nodes designed for present investigation are placed at each tank. Figure 10 depicts the installation of wireless sensor nodes at typical tank. As shown in figure 10 the temperature sensor is inserted into tank body through the opening of the test point and the temperature values are transmitted to the base station. Five nodes are located at tanks. Moreover, the established network is systematically presented in figure 11. As presented in figure 11, the five nodes are connected to the base station which is located at a specific distance away from the array of tanks. The distance between the two tanks is depicted in figure 11. The figure 11 also depicted the distance between actual tanks to the Base Station (BS). For wireless communication the star topology is deployed.

Figure.9 The Sylo-Milk chilling and storage section of the dairy SivamruthDoodhUtpadakSangh Ltd, Vizori, Akluj

5.A.2 Result and Discussion

The wireless sensor nodes sense the physical condition with the help of sensors, process the measured signal and disseminates toward the Base Station (BS). The base station receives the data, and upon receiving it, demonstrates it on the Graphical User Interface (GUI) and also stores into the database for further analysis. Further, the base station can be replaced by the router, which can send the data towards the control cabin. A care should be taken to locate the router at a site where the infrastructure interference may be minimum.


Figure 10 Wireless Sensor Node placed at Tank-5 for measurement of temperature

The WSN is established at storage tanks and instantaneous values of the temperature are recorded into the database. The temperature of the tanks shown by the system under investigation are plotted against time in minutes and presented in the figure 12.

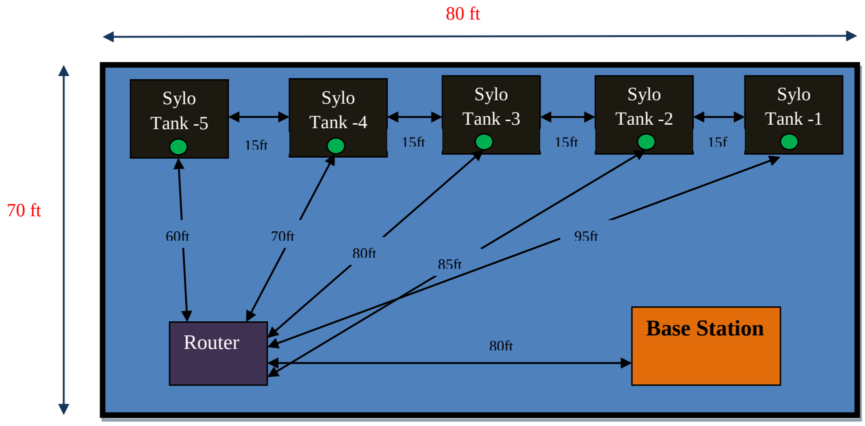

Figure.11 Schematic representation of WSN established at chilling and processing plant of the dairy

The wireless sensor network play commendable job of collection of data of site specific variability. The environmental temperature was about 27^0C to 29^0C. This gradient of the temperature may be due to location of the tanks. To obtain the temperature of the milk tanks, the temperature sensors are inserted inside through valves specifically designed to read the temperature of the tanks. On inspection of figure 12, it is found that, at the beginning the temperature recorded at base station was about 27 to 29 degree centigrade. This can be attributed to the ambient temperature of the tanks. On insertion of the sensor, the reading suddenly decreased and settled at the temperature of the tanks. Now, the nodes are disseminating the information regarding thermal status of the tanks. The WSN was established for different days and for different period of the day. However, the typical recorded from 11.50 a.m to 3.00 p.m data is presented in figure 12. During this period, it is observed that, the temperature becomes very low. The temperature at Sylo tank-3, wherein, sensor node-1 is connected shows the 14^0C temperature continuously. The temperature at Sylo tank-4, wherein, sensor node-2 is connected shows the 12^0C, while sensor node-3 which is placed at Sylo tank-5 shows the 14^0C continuously.

5.B. Deployment of WSN at the Refrigerator Section

In the dairy plant, at which various milk products are prepared, the refrigeration section is playing commendable role. Along with chilling of the milk, many other sections should be controlled at very temperature. This refrigeration section is providing cooling facilities to all other section. In fact ammonia gas is used to ensure the refrigeration mechanism. The section comprises ammonia gas compressors. Ammonia gas is highly controlled from its leakage. If the ammonia gas leakage take place, and if its concentration is more than the threshold level, then a catastrophic accident may happen. To avoid such accident, and to ensure proper security to the plant as well as to stake holder working in the plant, the gas leakage should be monitored properly. For precise, monitoring of ammonia gas leakage, the use of the WSN technology may be the suitable solution. Considering this fact into account, the present WSN is installed at ammonia gas compressor of the refrigeration section.

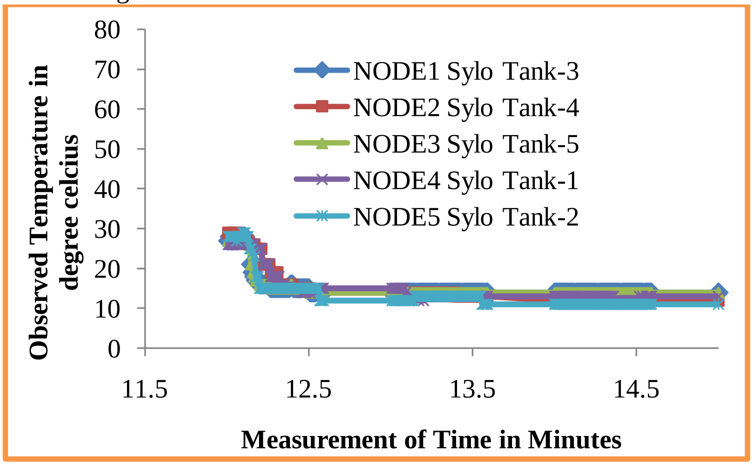

Figure 12. The Graph of Temperature at Sylo Milk tank section against time in minutes

5.B.1 Experimental Arrangement of WSN:

Experimental arrangement of installation of WSN at refrigeration section is depicted in figure 13. On this site temperature and ammonia gas is monitored through the sensor networks. Moreover, the system to alarm the leakage of NH_3 gas is available at each compressor.

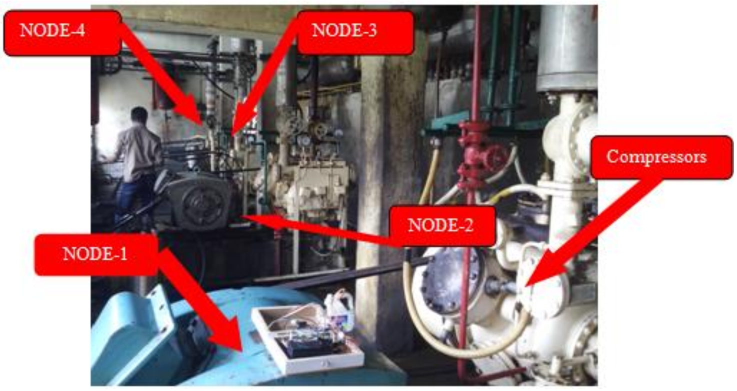

Figure 13 The experimental arrangement at refrigerator section for monitoring temperature and ammonia gas (NH_3)

Figure 14 shows the ammonia gas sensor of the installed at the refrigeration unit of the dairy plant. However, this system only provides the alarming if the leakage of the gas is above threshold limit. If the leakage of the gas is below threshold limit then it is not monitored and nor recorded as well. Moreover, a trace amount of ammonia gas if leaked then the system of the dairy plant is not responding. Therefore, to overcome these problems the WSN under investigation is installed at NH_3 gas compressor of refrigeration. The figure 13 depicts the experimental arrangement of the implemented wireless sensor network at refrigerator section for monitoring the temperature and ammonia gas. The results of implementation are interpreted.

Figure.14 The Photograph of the Amoonia gas Sensor of the dairy plant

5.B.2 Result and Discussion:

Implementation of the WSN at compressor of ammonia gas is schematically represented in figure 15. Therefore, to monitor the temperature and ammonia gas, the designed wireless system is implemented. At this site, wireless sensor nodes are placed, one for each compressor. The schematics depict exact positions of a compressor, sensor nodes and base station (BS). As shown in figure 15, the distance between each node is about 10 ft and the base station is located about 55 ft from the nodes. Walls of the refrigeration plant limit this distance otherwise, present WSN can operate with the periphery of 90m for indoor environment. It was found that both line of site and permanent structure like a machines, walls, furniture etc impedes the performance of the WSN.

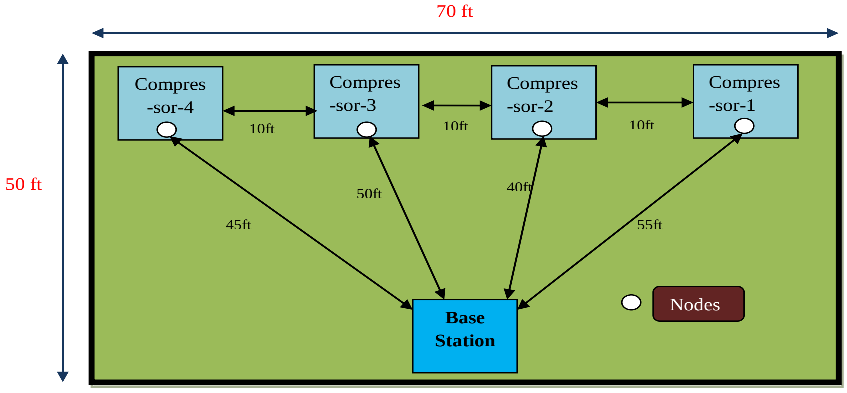

Figure 15 The Layout of the Refrigerator Section at Shivamruth Doodh Udapadak Sangh Maryadit.

The area of (70 ft × 50 ft) of this section is small. Therefore, the star topology is suitable for the wireless communication. Therefore, the star topology is employed to establish the wireless sensor network for the measurement of temperature and ammonia gas leakage. Further, a router can be placed at different location and the data regarding parameter values can be hopped towards the control cabin. The instantaneous values of environmental temperature is recorded at the base station and plotted against the time is presented in figure 16. Figure 16 shows the temperature recorded by all nodes, on inspection of figure 16, it can be said that, WSN is collecting the data of site specific variability.

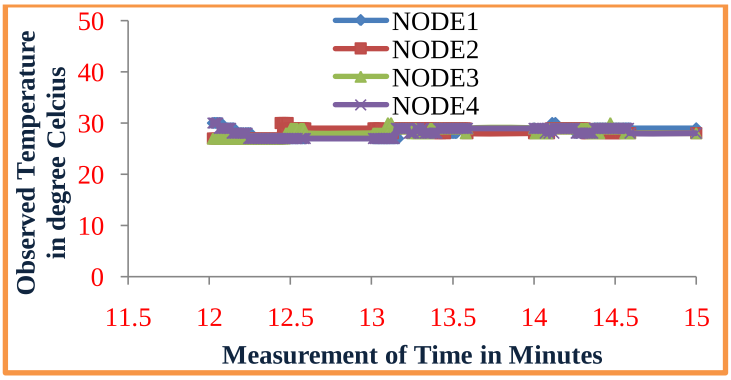

Figure 16 The Graph of Temperature values Measured at External Environment of Refrigerator Section against time in minutes

On inspection from figure 16, it is observed that, the environmental temperature at refrigerator section is varied in the range of 27^0C to 29^0C. The concentrations of ammonia gas (NH_3) sensed by the sensor nodes and collected at base station are represented in figure 17. On inspection from figure 17, it is found that, the concentration of ammonia gas, leaked into the environment near to the compressor is about 8% - 10%. It is found that, the threshold level decided by the sensing and alarming system of the dairy is about 30%.

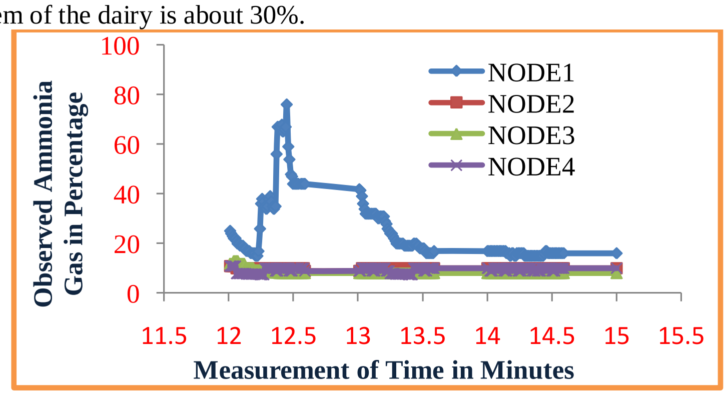

Figure 17 The Graph of Ammonia Gas (NH_3) values Measured at Refrigerator Section against time in minutes

Moreover, below 30%, the concentration of leakage gas is not only even monitored nor recorded. However, the WSN under investigation is more precise and it monitors the trace of NH_3 gas as well. The leakage of ammonia gas into the environment near to the compressor is about 8 to 10. Moreover, as the nodes move away from the point of interest, the concentration of NH_3 gas significantly decreased. This helps to realize the site specific data collection. However, the wireless sensor node-1 is placed at leakage point, where, the ammonia gas is leaked deliberately.

Figure 18 Photograph of the Leakage point of Ammonia gas (NH_3)

Figure 19 Photograph of the Milk Bag Filling section of the dairy industry ShivamruthDoodhUdpadakSanghMaryadit, Vizori,Akluj

The figure 18 depicts the experimental arrangement at ammonia gas leakage site. Therefore, the sensor node-1 shows the higher concentration of ammonia gas when leaked. The ammonia gas concentration is increased by increases the leakages of ammonia gas from the tank. Therefore, during the implementation it is found that, the concentration of ammonia gas is in range of 0-10% and it is not harmful to the human life. However, if concentration of ammonia gas is above 30%, then it is dangerous for human life and alarm should be triggered.

5.C. Deployment of WSN at Milk Bag Filling Section

The system under investigation is also implemented at milk bag filling section of the dairy industry, Shivamruth Doodh UdpadakSanghMaryadit, Vizori, Akluj. The figure 19 depicts the photograph of the milk bag filling section. As discussed earlier, the quantity of the milk in the milk bag is controlled by means of the weight of the milk. Keeping density of the milk constant to 1.026kg/liter [41], the weight of milk bag of ½ liter capacity is estimated to 513gm. To monitor the weight of milk bag the WSN under investigation is implemented and results of implementation are presented.

5.C.1 Experimental Set-up:

With the view to monitor, the weight of milk bag, online, the WSN under investigation is implemented. The experimental arrangement is shown in figure 20. As depicted in figure 20, the wireless sensor node, of present WSN, is arranged in such a way that the milk bag can immediately convey on the pan assembled on the load cell. As milk bag comes on the pan, the weight of bag is measured and the data disseminated towards the base station.

Figure 20 The Experimental Arrangement of the Wireless Sensor Network at Milk bag filling site.

5.C.2 Results and Discussion:

During experimental period, the machine is filling milk bag with ½ liter milk. After filling the bags get sealed and conveyed out through conveyor belt. The rate of bag filling was 12 bag/minute. It is found that, the weight of the bags is checked manually and the checking is not carried out in real time. The weight is measured by using traditional weighing machine. A significant of time is required to obtain the weight of the bag by adopting traditional method. Within this period large amount of milk bags may be conveyed out without checking the weight. To avoid the traditional weight measurement system and to ensure on-line monitoring, the present WSN is established. The WSN under investigation measures the weight of the milk bag, continuously with the help of sensor node and transmits the measured parameters wirelessly towards the base station. The area of the milk bag filling section is 1500 square foot. The nodes are located at output stage of the conveyor belt. Moreover, the distance from nodes and base station is about 40 ft.

It is also suggested to replace base station with the router and router can wirelessly interact with the base station located at the controlling cabin. The system is also deployed to monitor the temperature of the environment.

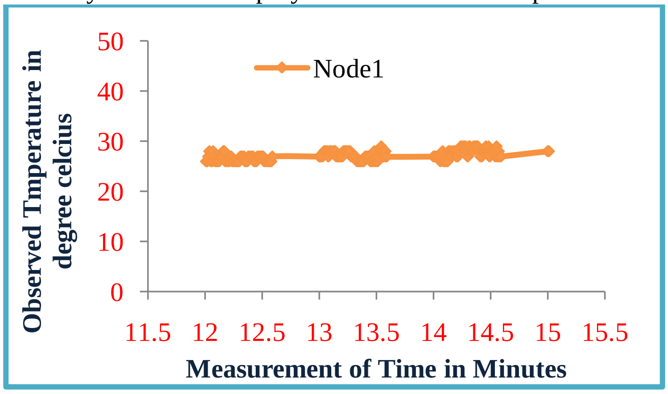

Figure 21 The Graph of Temperature values Measured At Milk Bag Filling Site against time in minutes

The results of the weight measurement are recorded at the base station (BS) and represented graphically. The figure 21 depicts the temperature values at milk bag filling site. On inspection of figure 21, it is observed that, the temperature varies in range of 26^{0}C to 29^{0}C. The figure 22 depicts the recorded weight of the milk bags for ½ liter (513gm).

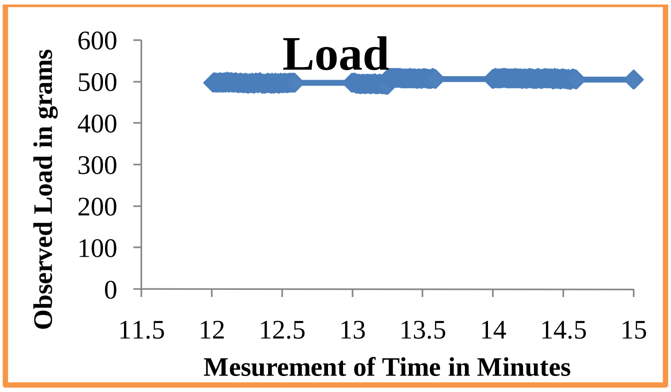

Figure 22 The Graph of Weight of ½ liter milk bag Measured at Milk Bag Filling Site against time in minutes

VI. CONCLUSION

Emphasizing industrial needs, the Wireless Sensor Network is developed to monitor typical industrial parameters such as temperature, leakage of ammonia gas, weight of the finished product etc, wherein the sensors nodes are developed about ARM LM4F120H5QR microcontroller. Deploying sensor modules of promising features, the transducer interface section is developed. Ensuring the philosophy of the embedded technology, the nodes have been designed, wherein the zigbee devices are used to realize the wireless networking in which the standards of IEEE 802.15.4 are followed. The nodes have been calibrated to real units and standardized with sophisticated instruments. To realize on-site implementation the WSN under investigation is deployed in the environment of the dairy plant to collect the information of the said parameters. The WSN is deployed at Refrigeration section, Milk storage and Chilling section and Milk packetization unit. The data regarding leakage of ammonia gas at refrigeration section, temperature of the chilling tank and weight of the milk packet is monitored on the dedicatedly designed GUI at base station. The results obtained are in close math with the standard results, which revealed the reliability and preciseness of the WSN under investigation.

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