Design of Wireless Sensor Network (WSN) and Human Machine Interface (HMI), for Industrial Fuel Storage and Distribution Systems

Er. Chinmaya Panda[1], Prof. R N Patil[2]
[1, 2] Department of Electronics & Telecommunication Engineering
[1, 2] Marathwada Institute of Technology, Aurangabad, Maharashtra, India

Abstract- *Due to advancement in sensor technology, intelligent low cost processors and efficient wireless radios, interconnecting various devices through wireless protocols attracts most technologists and it might be an affordable alternative of wired communication. In this paper Liquefied Petroleum Gas (LPG) and High Speed Diesel (HSD) storage and distribution plants has been take under consideration and prototype has been designed to test physical implementation complexities. Digital and Analog data from remote operational stations have been transmitted through Zigbee based wireless modules to centralized control room for Supervisory Control and Data acquisition purposes. Different methods of designing WSN systems have been compared and informative conclusion has been put forwarded from hardware and software prospective. We found that, receiving erroneous data and updating of erroneous values in designed Graphical User Interface (GUI) is nearly 0 and the overall system has standard deviation of receiving remote data is nearly 6. Along with comparison of different wireless data transmission algorithms, detailed system design have been explained so that similar type of systems can be designed by other technologists. Most probably in near future, WSN technologies might be complete replacement of wired systems due to its techno-commercial advantages.*

Keywords- Arduino DUE, Diesel Plant, Flame detector, Gas Detector, HMI, LPG Plant, SCADA, VB.NET, Wireless Sensor Network, Zigbee.

I. INTRODUCTION

Human is the best creation in this planet. He has best capability of innovation and adaptation. Due to rapid increase in population the demand of products and basic human needs are increasing. So to fulfill basic needs industrial revolution for mass production is the ultimate result. Maximum of the industrial processes take place under high temperature or noisy environment or even chemical reach toxic environments. So every industry requires automation system to keep process running. Again the existing technology of industrial automation and process monitoring also revolutionizing and expecting a better solution to overcome from present hardware centric and wired solutions to software centric and wireless solutions. Engineers, technologists and researchers are working together to develop a better solution from existing non flexible wired communication technology.

A. Necessity of Wireless Sensor Network

Interconnections between different remote areas are necessary to control and monitor from a single location. Most convenient way to interconnect machineries or equipments is wired connection. For wired connection we require instrumentation cable, communication cable like cat7, fibre optic so on. To protect and support cables we require cable tray, cable tray support and other accessories. In case of buried cable future repairing work becomes a challenging task and overhead cables creates obstacle in vehicle and other transportation activities. For future modifications or relocation of machineries it imparted huge cost and some cases old system need to be scrapped by new installation.

Due to rapid development of digital CMOS technology, price of wireless radios are decreasing continuously, so migration from wired to wireless technology is obvious. Future modification, relocation, addition or removal of equipments is flexible. Even technological developments make it possible to troubleshoot and reprogram the remote systems.

B. Objective

This Project work is completely focused on Core Industries like Aluminum, Steel, Power, Petro Chemical, Glass, Pharmaceutical, Plastic, like manufacturing companies. Any ideal core industry can be categorized in to several core functioning areas. Prime concern of any organization goes to qualitative product, so final product or base product manufacturing, processing and packaging comes under Production section. Other functional areas are meant to support production. These sections are known as Utility. Most required Utility is Energy. Energy might be available in form

of Electricity, Fuel, High pressure dry air or high pressure fluids.

Most important form of energy is Fuel. In fuel handling section we require to store and distribute Gases like LPG, Propane, NG like flammable gases and liquid fuels like furnace oil, diesel, petrol, HSD. This section has considered as most critical due to presence of flammable gases in environment. Instruments found in these regions are of special kind with flame proof design, generally known as intrinsically safe Instruments.

II. PRIOR WORK

Lot more effort have been taken by different technologists and researchers to give reality to wireless technology. Many engineers had successfully implemented WSN technologies in Home Automation and sort distance communications. Industrial implementations need much more refinement in technology.

Mr Hung Cheng Chen of National Chin-Yi University of technology [1] had implemented Zigbee based energy monitoring system at his own university. He had used digital watt meter to get real energy consumption of different departments. All energy meters of each department was connected by using RS485 protocol with TI cc2430 module and JN5121 Zigbee module (Jennic Company). Zigbee modules communicate with central Zigbee/GPRS gateway (G-4500, manufactured by ICP DAS). Finally the signal was received by GPRS Router which is connected to PC, where Visual Basic Software is running to visualize energy parameters of different energy meters.

Dr. Raymond S. Wagner of Johnson Space Center, NASA, [2] has published a very good real time implemented paper related to implementation of IEEE 802.15.4 for space flight applications. In his paper he have compared 3 different wireless radio protocols like Zigbee, Wireless HART, ISA100.11a. final prototype was tested by using TI MSP 430 processor and ready to use WSNradio manufactured by Crossbow. He was not happy with the performance of the IEEE 802.15.4 modules performance due to lot more issues like interference with wifi frequency, signal dropping and so on. This paper is very informative and have good explanations of all 3 types of protocols.

Mr. Arther Low [6], had well explained the evolutionary developments in wireless radio technologies and compared technical aspects of 2 wireless protocols like wireless HART and ISA100.11a.

III. SYSTEM MODELING

A. Hardware Selection

Hardware used in industrial wireless sensor network related projects are intended to work in harsh industrial environment and information Trans-receive should be reliable. Care need to be taken so that selected hardware should not obsolete or Product discontinue. So it's advisable to use readily available ARM based most advance development boards.

After comparing few potent development boards available for prototyping, it has been concluded that Arduino DUE is most reliable development board. The reason to select Arduino DUE is that the hardware design is open source, so the product is easily available with low cost and rare chance of product discontinuation. As extra butter on bread even the Software IDE is also Open source and easy to use. Program development time reduced effectively due to Arduino IDE as, maximum of required libraries are included in IDE, so no need to refer microcontroller datasheet to find pin configurations, register details, flag details. It's not necessary for embedded developers to think about the hardware they are using, rather they can use the benefit of software to complete their tasks, and mean time the back ground software will take care of hardware details.

B. Wireless Radio Selection

The most critical aspect of selection of wireless module is its cost, availability, compatibility and reliability. These modules are of huge cost, easy to damage, and less frequently available. When we think the real time implementation of wireless technology in industries then we need to think the licensing aspects also. So our wireless radio should use license free band, at India it is 2.4 GHz for IEEE 802 modules. Three most common designs are available based on IEEE802.15.4 standard like Wireless HART, ISA100.11a and Zigbee. Zigbee is most popular hardware radio architecture for NET & APP layer. Again Zigbee has different modules like Xbee s1, s2, s2b, s2c, Pro s2b, Pro s3b so on. Starting from 2mW to 63 mW designs are available, with range from 60 meter to 45Km if we use Xbee Pro s3b with high gain RPSMA dipole antenna. Most interesting thing is the Xbee modules are working in 3.3V DC and my hardware is also of same range, so no need of external voltage conversion ckt. To decrease the overall expenses in project development, low price modules used like Xbee S2 2mW module costs 1300 rs. Obviously its range is less but for initial project prototyping it can be used. Most interesting fact is that, all available modules of S1, S2, S3 are pin to pin compatible,

so no need to change a single wire in final design. Xbee modules should be programmed before using it. Also we need to set topology. In simple language we can say we need to configure the transmitter and receiver by providing each other's address. XCTU NG software and Xbee USB adapter board are used to configure these modules.

C. Software Selection

There are lots of options we have for software development like, Java, HTML, C++, VB, MySQL, MS Access…etc. But finally VB.NET 2015 is selected for prototyping. This software helps developers in a very innovative way. We have to design the external objects or GUI, then double clicking on each component will create a ready to use program known as sub class. The programmer needs to write the function or action need to be done by the object.

Finally It can be concluded that in this project Arduino DUE development board is used to interface external hardware or machine and wireless radio. Xbee series 2 is used as wireless Radio and VB.NET 2015 is used for designing GUI.

IV. SYSTEM DESIGN

In wireless sensor network we need to define different available wireless units and called as Node. Each area of industry or nearer equipments are connected each other to form Node. In simple way we can define a Node as a hard wired system connected with certain microcontrollers with a wireless radio. In wireless sensor network (WSN) Node should be separated or there should not be any wired connection, each node should be portable, battery operated and low power embedded system, which inter connected with real time environments or machineries to gather required information and send the raw or processed information to specific remote device.

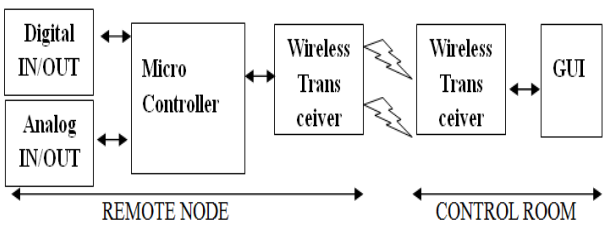

Figure IV.1 Generalized Block Diagram

A. Remote Node Design (Node-2)

Node-2 is designed for fuel distribution system. Initial simulation design has been carried out by using Proteus software package.

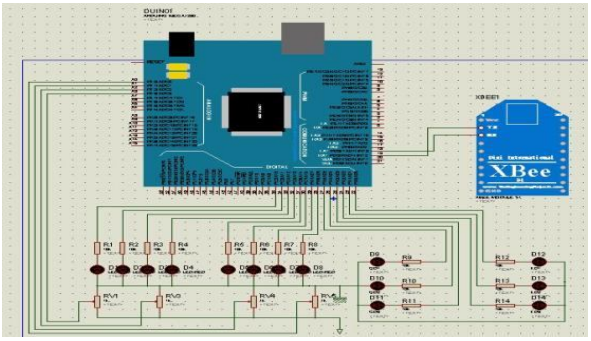

Figure IV.2 Proteus Design of remote Node

After Proteus design hardware wiring has been done. Basically for test purpose LPG storage tank Level, LPG tank pressure, Diesel Tank Level and pressure are considered. These analog values has been compared and to facilitate local display 4 status LED has been provided. For each 25% rise in level one status LED will glow so that operator can get approximate estimations.

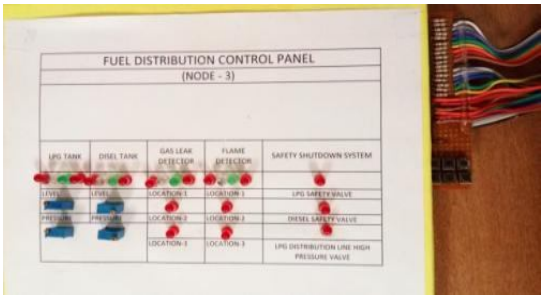

Figure IV.3. Node-3 LOP

Due to presence of flammable gases safety alarm system (SAS) has been implemented. In case any gas leakage or flame detection concern indication will active and operator will aware by alarming system.

Figure IV.4 Remote Node GUI

Remote node sends data to central Node present in Central Control Room. To visualize received data and remote plant status Graphical User Interface has been designed by using Vb.Net 2015 community edition. Designed GUI has capability to trans-receive both analog and digital data. LPG, Diesel level and pressure are analog value. Whereas status of gas leak detector and flame detectors are of digital value.

B. Program flow:

Status of process variables or input/output status will be available to Arduino DUE and as per programming it will update status variable value. This status variable will transmitted through UART or serial port 1. As per designed protocol Xbee end device will send data to Xbee coordinator which is connected to central node.

Received string by Xbee coordinator is made available to Arduino DUE then transferred to PC via Com Port. VB.Net program accepts all data from serial buffer and compare each field. If string is valid then it updates the corresponding field of GUI.

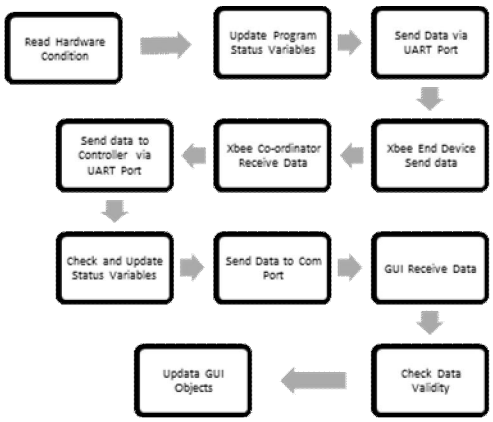

Figure IV.5. GUI Program Flow

In GUI option is available to select the serial port to which our wireless radio or the microcontroller development board is connected. Also we can see all receiving data in Rich Text box available in GUI, so that we can calculate required performance metrics and troubleshoot communication related issues.

V. SIMULATION AND RESULT

We need to configure Xbee Modules, so that they can communicate. In this prototype point to point communication between two xbee modules has been established. To configure Xbee modules XCTU NG software package has been used.

We need to Run the GUI, select the serial port and press the “Connect” button. After a valid selection, SCADA will start acquiring data from selected Serial Port. And compare it’s initial key letter i.e ‘C’. If letter C has been received as an initial key letter then rest of all received values till new line character is stored in an array and this array values has been used to update GUI.

Figure V.1. Fuel Distribution system GUI

Status updating in SCADA takes less than 5 second, these delay is due to Timer Tick operation of VB.NET software and Programmed delay in Arduino.

A. Power Consumption

To calculate power consumption two multimeters have been used, one is for measuring supply voltage and other is for measuring current. As whole system is a digital system so power (P) is equal to product of voltage (V) and current (I).

P = V * I (in mili Watt)

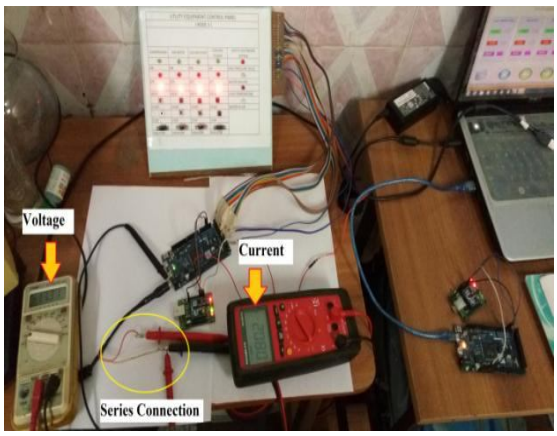

Figure V.2. Power consumption measurement Hardware setup

A.1. Procedure for Measuring Power

Connect all components and make sure that all set of equipments are in operational condition. In this condition as whole circuit is in operational condition so voltage and current

measured is of full load condition and power measured is known as full load power consumption.

Table V.1. Power Consumption

Sl. No.	No of Samples	Valid Data	Missed Data Samples	Accuracy	Error	(Xi-Xavg) 2
1	45	39	6	86.7	13.3	9.94
2	52	47	5	90.4	9.6	0.32
3	67	59	8	88.1	11.9	3.10
4	73	68	5	93.2	6.8	11.09
5	98	89	9	90.8	9.2	0.99
Average Accuracy					89.82	
Standard Variance					11.38	

Then remove each set of equipment and measure voltage and current. By using full load current, no load current and present measurement we can calculate power consumption of each component.

Table V.2. System Performance Metric

Sr. No.	Component	Current (I) in mV	Voltage (V) in Volt	Power (V*I) In mW
1	Arduino DUE	66	11.43	754.38
2	DUE + Xbee (Sleep)	69.2	11.39	788.188
3	DUE + Xbee (Active)	76.2	11.25	857.25
4	DUE + Analog I/O	79	11.22	886.38
5	DUE + Digital I/O	79	11.22	886.38
6	Full Load	85	11.17	949.45

B. System Performance Analysis

Five experimental observations has been noted, by keeping Xbee modules within 5 meter range. VB.Net should receive starting letter "C" followed by 4 analog values and 6 digital values. System accuracy and standard deviations has been calculated as shown in bellow table.

$$\text{Accuracy} = \frac{\textit{No of valid Data String}}{1!\textit{Total no of string received}} * 100$$

$$\textit{Variance of System} = \frac{1}{\sqrt{n}}\sum_{k=0}^{n}(X_i - X_{avg})^2$$

Due to efficient System programming and discard of erroneous data the Overall System accuracy is 90%.

VI. CONCLUSION

This project is a small advancement in implementation of WSN technology in industries. As per feedback given by industry experts, this system could be implemented in core manufacturing industries. After vigorous system testing, it has been concluded that the overall system accuracy is nearly 90% with standard deviation of 6. Highest power consumption is nearly 1 W. As per this project's core idea, power consumption is not an important factor as the existing industrial equipments consume lot of power and electric supply is readily available for equipment operation. SCADA used in this project is intuitive and mimics exact industrial monitoring systems.

As per experimental observations it is true that general purpose Xbee modules (S1,S2- 2mW series) are not well capable to trans-receive data if Wireless modules are placed at Out of Site. Maximum time it drops connection if distance is high. Better operation without uninterrupted communication is observed within 100 meter of range.

Finally it was concluded that overall system performance is as expected. If wireless communication range can be improved then probably this system might be implemented in industrial environments along with existing control system.

FUTURE DEVELOPMENT

The empty space of WSN needs to be filled with endless possibilities. As commercially ready to use wireless modules are under critical refinement, so engineers are enthusiastic for a better hardware in near future. Even though we can connect existing control systems like old PLC & SCADA system with receiving node of WSN or Zigbee Coordinator. Even we can implement client & server side programming to visualize the system from remote locations. We all knows that embedded systems can't recover from some deadlock conditions and can't heal itself, so interested researchers can port Real Time operating System like FreeRTOS or uCos, into the microcontrollers. This project can be implemented in several industrial applications, home automation and public sectors units.

REFERENCES

[1] Hung-Cheng CHEN, Long-Yi CHANG,"Design and Implementation of a ZigBee-Based Wireless Automatic Meter Reading System", Electrical Review, National Chin-Yi University of Technology, 2012

[2] Raymond S Wagner, "Standards-Based Wireless Sensor Networking Protocols for Spaceflight Application", IEEE Aerospace Conference, March 11 2010.

[3] Miguel Garcia, Diana Bri, Sandra Sendra, Jaime Lloret, "Practical Deployment of Wireless Sensor Networks:a Survey", International Journal on Advances in Networks and Services, Vol. 3 no 1&2, 2010

[4] Mark Hempstead, Michael J. Lyons, David Brooks and Gu-Yeon Wei, "Survey of Hardware Systems for Wireless Sensor Network", Journal of Low Power Electronics, Vol. 4, 1-10, 2008

[5] Ananya Chatterjee, Manjusha Pandey, "Practical Applications of Wireless Sensor Network Based On Military, Environmental, Health And Home Applications: A Survey",International Journal of Scientific & Engineering Research, Vol. 5, Issue 1, January-2014

[6] Arthur Low, "Evolution of Wireless Sensor Networks for Industrial Control", Technological Innovation Management Review, May 2013

[7] F. L. Lewis, "Wireless Sensor Networks", Smart Environments: Technologies, Protocols and Applications, Automation and Robotics Research Institute, University of Texas, Arlington, 2004

[8] Vehbi C. Gungor, Gerhard P. Hancke, "Industrial Wireless Sensor Networks: Challenges, Design Principles and Technological Approach", IEEE Transactions on ndustrial Electronics, vol.56, no10, pp. 4258–4265, 2009.

[9] Maximilian Riegel, "IEEE 802 Introduction and Overview", Siemens Moblie, ICM N Advanced Standardization, 11-03-2004

[10] Lamia Charri and Lotfi Kamoun, "Performance Analysis Of IEEE 802.15.4/Zigbee Standard Under Real Time Constraints", International Journal of Computer Networks & Communications (IJCNC) Vol.3, No.5, Sep 2011

[11] Xie Lu, "Supervisory Control and Data Acquisition System Design for CO2 Enhanced Oil Recovery", Technical Report No. UCB/EECS-2014-123, Electrical Engineering and Computer Sciences, University of California at Berkeley, May 21, 2014

Biography

Er. Chinmaya Panda

His native is nearer to Chilika Lake of Odisha, India. He received his B.Tech degree in Applied Electronics & Instrumentation Engineering from GIET, BPUT University, Odisha in 2011. He is having 5+ yr of rich experience in Electrical & Instrumentation Maintenance department of various Multi National Companies. He have skill in Project commissioning and ISO activities. At present He is a student of M.Eng., in Embedded Systems department at MIT, BAMU, Aurangabad, India. His research interests include Industrial Automation, Instrumentation, Embedded System Design and Machine to Machine Wireless Connectivity.

Prof R. N. Patil

He is the resident of Aurangabad, Maharashtra, India. He received his B.E. in Electronics & Telecommunication Engineering from, JNEC, Aurangabad in 1996. He also completed his ME in Electronics from Govt. Eng. College, Aurangabad. He is having rich industrial experience. He also completed his Masters of Management Science, From Pune University. At present he is working as Associate Professor of E&TC dept, MIT, Aurangabad. His research interest is in Wireless Communication.