Wireless multi-sensor embedded system for Agro-industrial monitoring and control

Chandani Anand, Shashikant Sadistap, Satish Bindal, B. A. Botre and KSN Rao
Central Electronics Engineering Research Institute (CEERI) Pilani-333031, India
Council of Scientific and Industrial Research (CSIR)
e-mail: Chandnianand_ddu@yahoo.com, ssadistap@yahoo.co.in, bindalonline@yahoo.com, bbotre@gmail.com, ksn@ceeri.ernet.in

***Abstract*— The paper presents a development of the multi sensor embedded system for measuring up to eight sensor parameters optimized by appropriate algorithms. Since most of the industrial applications use the analog sensors with transmitters for sensing the process parameters particularly in harsh environment because of their strong mechanical packaging and ruggedness. Then the benefits of digital technology in the vast world of analog sensors can be implemented by development of appropriate multi sensor embedded system. The developed system has most of the features of smart sensing and communicating to other embedded/Host PC through a wireless interface. The developed prototype system has been tested with RTD temperature sensors for temperature measurement over a wireless connectivity for various distances. From an application point of view, a mobile robotic platform is developed to test the multi-sensor embedded system for Agro-Industrial Applications. Further, the average loss in signal is measured and received power is calculated and compared. Finally, the effect of obstacles at indoor and outdoor range for wireless transmission has been presented. It is observed that for better transmission of signals via wireless communication, the low frequency along with low baud rate and line of sight range is required to minimize the signal loss.**

Keywords- Embedded System; Sensors and Actuators; Wireless Mobile Robots; Zigbee Wireless Connectivity

I. INTRODUCTION

A "smart sensor" is a transducer (or actuator) that provides functions beyond what is necessary to generate a correct representation of a sensed or controlled quantity. The "smart sensor" functionality will typically simplify the integration of the transducer into applications in a networked environment [1]. Embedded with a microcontroller unit, a smart sensor has much more built in intelligence over a traditional sensor. So, it can perform more powerful functions such as self-identification, self–calibration, converting the raw sensor signal into a digital form . Multi sensor systems are now used in many application areas, including environment and habitat monitoring, healthcare, home automation, and traffic control especially in agro and food applications like Reverse Osmosis (RO) plant automation, fish pond management systems, environmental monitoring, precision agriculture, machine and process control, building and facility automation. Wireless based Smart sensor module has drawn attention of the industry on account of low cost, low power consumption, flexibility, and use in remote areas.

Precision farming is the conjunction of a new management perspective with the new and emerging information and communication technologies leading to higher yields and lower costs in the running of large scale commercial agricultural fields. Further, the embedded sensing technologies allow the identification of pests in the crops, increased moisture or drought at a real-time interval with automated actuation devices to control irrigation, fertigation and pest control in order to offset the adverse conditions. The Precision farming system incorporates: a) Sensing agricultural parameters b) Identification of sensing location and data gathering c) Transferring data from crop field to control station for decision making and d) Actuation and Control decision based on sensed data.

Over the last few years, the advancement in sensing, embedded technology and wireless communication technologies has significantly brought down the cost of deployment and running of a feasible precision agriculture framework. Emerging wireless technologies with low power needs and low data rate capabilities, which perfectly suites precision agriculture, have been developed [2, 3]. Agricultural Sensors, positioning systems for detecting location of sensors, actuators like sprinklers, foggers, valve-controlled irrigation system, etc. are also reported in the literature. However, very limited work has been done so far on the wireless multi-sensing system to be used to transfer sensor data wirelessly from crop field to the remote central PC.

In this paper development of a low cost multi sensor system for sensing eight input analog sensors along with reconfigurable automation, and communicating with host (wired and wireless) is presented. The proposed smart multi sensor system is an attempt to develop a generic platform with 'plug-and-play' capability to support hardware interface, communication, needs of multiple sensors, and actuators. The system has been implemented using our own developed eight potentiometer based kit and tested with resistance temperature detector (RTD) sensors for sensing, decision-making and their control in order to reduce the false alarms and unwanted process shut downs. The data sent using wireless communication makes system efficient, effective and intelligent decisions based on processed data that is accurate and analyzed. Wireless communication has its own advantages like Ease of installation; no bulky cables are needed and simplify design of systems. In this paper, we introduce the new smart sensor device with processing and communication as well as various sensing abilities for industrial and agro – based monitoring applications.

Further, considering the potential application of this field, the present extended work details on the development of wireless mobile robotic platform for farm sensing is also presented [4]. The organization of this paper is as follows. Section 2 covers related work on wireless communication based smart sensors related to agro, food and other applications. Section 3 gives the system description. Finally, Section 4 covers experimental results of the current implementation and Section 5 includes conclusion and future work.

II. RELATED WORK

There are many projects undertaken and many researches proposed the development of smart sensors and their networking. The design and implementation of home network based on smart sensor devices focuses on the development of system for home purposes where it can be implemented for door lock system, gas detecting system, controls TV, refrigerator, and outlets, and applying RFID into home networks [5]. The development of smart sensors for pollutant gas detection like CO and LPG where a CO gas detector is developed and controlled by smart sensor to give alarm if gas generation is above the set limit and used in home, institutions and industries [6, 7]. The Motes and Smart Dust project at UC, Berkeley focused on creating low-cost micro-sensors, with emphasis on the development of sensors and an embedded operating system, Tiny OS . Recently, the wireless sensor networking is used for life science automation where they propose a wireless sensor network (WSN) especially dedicated to the field of life science automation (LSA), which can be used for multiple purposes [8]. This area provides a bulk of process and environmental parameters, which have to be controlled. Passel and Danzer developed a portable, mobile instrument to measure temperature, relative humidity, noise, brightness and ammonia content in the air within the house and transferred the data wirelessly to a PC through an infrared data link [9, 10, 11].

In precision agriculture, the most important step is the generation of maps of the soil with its characteristics. These included grid soil sampling, yield monitoring and crop scouting. RS (remote sensing) coupled with GPS, coordinates and produce accurate maps and models of the agricultural fields. The sampling was typically through electronic sensors such as soil probes and remote optical scanners from satellites. The collection of such data in the form of electronic computer databases gave birth to the GIS. Statistical analyses were then conducted on the data and the variability of agricultural land with respect to its properties was charted. The technologies used are expensive like satellite sensing and was labor intensive where the maps charting the agricultural fields were mostly manually done. Blackmore et al., in 1994 [12] reported a comprehensive system designed to optimize agricultural production by carefully tailoring soil and crop management to correspond to the unique condition found in each field while maintaining environmental quality. Further, only large farms could afford the high initial investment in the form of electronic equipment for sensing and communicating. The technologies proposed at this point comprised of three aspects: (a) Remote Sensing (RS), (b) Geosynchronous Positioning System (GPS) and (c) Geographical Information System (GIS).

The system we have developed is useful because various physical parameters can be sensed and manually controlled on automatic false detection, as well as eight parameters can be manage precisely via single micro controller. Finding the better location and minimum loss in signal for wireless communication to device, makes the system more challenging and applicable [13].

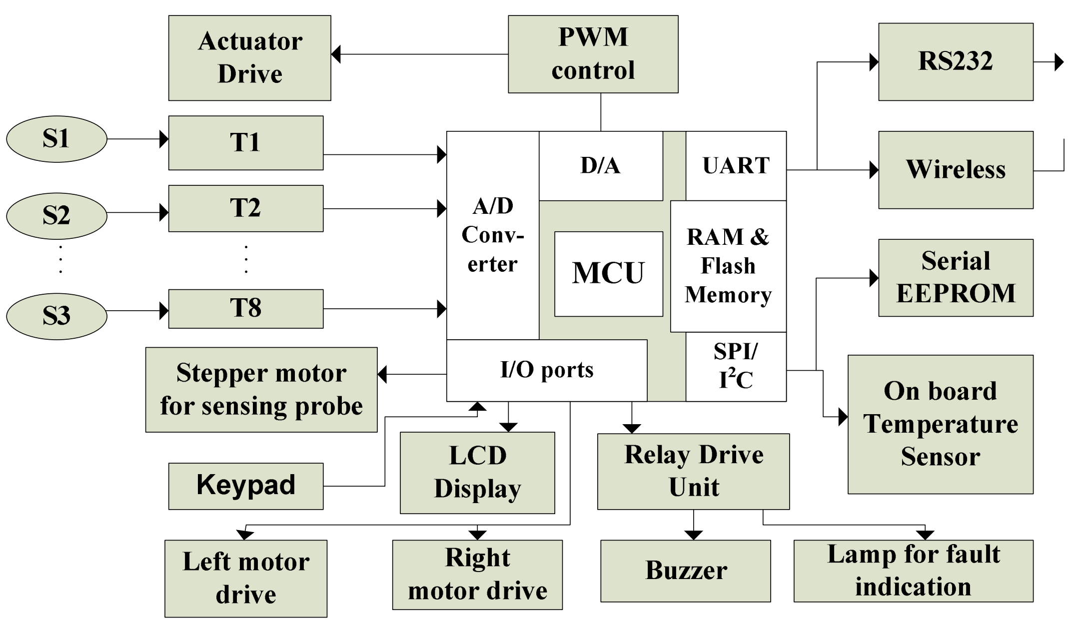

Figure 1. General Architecture of developed system.

III. SYSTEM DESCRIPTION

The generic architecture of system is shown in figure 1. It consists of eight sensors with transmitters. To make the system more compact MICROCHIP's 8 bit PIC18f452 has been used which has most of the peripherals on chip. It has low power consumption, fast executing speed and on chip 1536 bytes of flash and 256 bytes of data EEPROM memory. It can operate up to 10MIPS (DC to 40MHz). There are 18 interrupt sources, two-timer modules, two capture/ compare / PWM modules, 8x8 hardware multiplier and master synchronous serial port module having SPI and I2C interface. On chip serial communication supports both RS232 and RS485. The system can work up to 40 MHz clock frequency. But response time of many sensors is of the order of 100µs or more [12]. So, a processor speed of 10MHz to 15MHz should be adequate. Considering the optimum performance and cost of the overall system and due to easy availability of crystal oscillators up to 16MHz, the system clock of 10 MHz is selected for current application. There is 10 bits, 8 analog input channels A/D converter with acquisition time 12.86µs. The eight input sensor nodes operate under stored program control [14]. The micro controller A/D converter performs periodic scans of these sensors. The scan rate is programmable and can be adaptive based on the rate of change of sensor reading. The sensors data are compared with set-point values stored in memory.

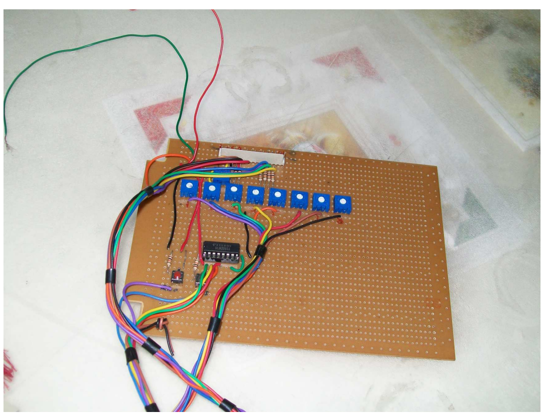

Figure 2. Eight potentiometer based kit.

For testing of eight channels, an eight potentiometer based kit has been developed in laboratory shown in figure 2. The parameters are firstly checked with eight potentiometer kit and then module has been checked by RTD sensors. The eight potentiometers are connected at PortA, analog input channels of microcontroller. Voltage (0-5V) is converted into corresponding engineering units for different parameters. The control of system can be done by two switches (RB0 and RB1) connected on port B of microcontroller. The value of parameter one (0 - 1000PPM) can be adjusted by first potentiometer and when switch RB0 is pressed it comes to the set point value for first parameter which is already stored in flash memory. The set point value can be increment or decrement (0-1000PPM at span of 100PPM) by pushing switch RB0 according to user's need. If switch RB1 is pressed, it escapes from set point routine and automatically compares set point and parameter value to give alarm indication if sensor parameter value is greater than set point values and parameter value can be adjusted, if needed. Similarly, using second potentiometer, parameter two is tested and set point value can be set for second parameter. If another parameter has to be set among eight parameters, the processor can switch to them periodically in similar manner by pressing key RB1. Alarm acquisition is done by open collector source ULN2003 (transistor array).

In between all process, the processor continuously checks if character '*' has been received from keyboard, then it transmits all parameters and set point values to the hyper terminal as shown in figure 3 and come back to the main program. All measured data is stored in on chip Flash and also serial EEPROM has been interfaced via I2C bus to utilize the non – volatile memory. All values are transmitted to LCD unit using the LCD interface. The parameter values and their set - point values can be transmit via RS232 or wireless module (DIGI's X-Bee – PRO 802.15.4 transceiver) which has capability to transmit data up to 1.6 km line of sight at frequency 2.4 GHz. In general, a lower frequency allows a longer transmission range and stronger capability to penetrate through walls and glasses [3]. However, the GHz bands of 2.400-2.4835 are worldwide acceptable. The microcontroller apart from the measurement of analog parameters [5] also performs all the required housekeeping tasks and interacts with the other peripherals. A battery supply monitoring circuit generates an interrupt on detection of a battery fail condition and initiates an emergency measurement backup. There are two main time intervals that need to be maintained. The sensors with their transmitters are carefully timed using software timers. Assembly and C language programming is done using MPLAB IDE tool along with PICDEM-2PLUS debugger and programmer for implementation of developed algorithms, monitoring and display of parameters and set point values.

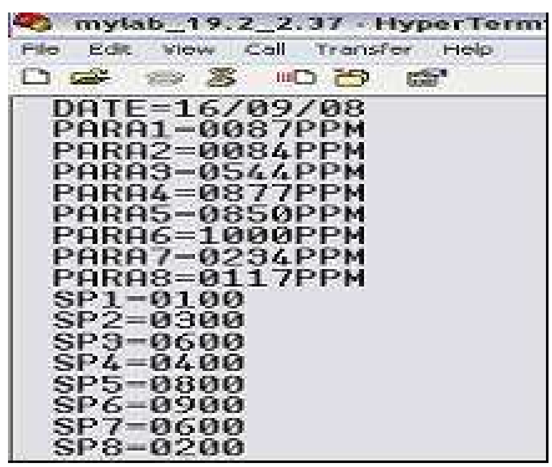

Figure 3. Data transmission at hyper terminal.

The developed multi-sensing system performs both tasks viz. sensing of parameters as well as controlling the movements of the mobile robot using left and right DC motors [14]. The summary of hardware configuration for mobile multi-sensor embedded system is as follows:

- Central PC: Data acquisition using wireless communication and analysis
- PIC18F452 – 4 MHz, RAM 1.5kbytes, flash program memory – 32kbytes, 8 channel - 10-bit A/D converter for sensor and motor control
- Soil temperature and humidity measurement using sensor s LM335 and RDT respectively
- ZigBee/802.15.4 RS232 RF Modem – wireless connectivity between mobile robot and central PC
- Two DC motors: Supply voltage 12V, 6mm shaft diameter, 30 RPM
- One stepper motor: for mobile robot arm for sensor assembly
- Stepper motor driver: 1 L293. Battery: 12volt, 3.6Ah

The temperature sensors LM335 and RTD are mounted on the robotic arm assembly. The sensors calibration circuitry is also included in the design. The sensor interface circuit to PIC18f452 is composed of unity gain amplifiers followed by a filter circuit to reduce the loading effect and noise respectively. The filtered signal is given to the A/D converter for sensor signal digitization.

The motor driver circuit is designed to drive DC motor and stepper motor. The stepper motor for arm is driven in half stepping mode, so that the effective step angle is 1.8 degrees. IC L293 is used to drive the DC and stepper motors, which limits the current up to 600mA.

A. Temperature measurement

The temperature measurement is implemented using the PT100 Resistance Temperature Detector (RTD) sensors [15]. The transmitter circuit takes RTD as input and provides 4-20mA output corresponding to the measuring range of 0-50°C. The XTR-103 has built-in provisions for RTD current excitation, signal amplification and liberalization on a single integrated circuit. The zero and span adjustment are carried out to get 4-20mA output signals for a working temperature range of 0-50°C. These 4-20mA current signals are interfaced to the ADC input port of the micro controller for further processing. First, temperature transmitter circuit is calibrated by connecting a standard resistance box. The resistance is set to 100Ω, corresponding to 0^oC, and then ZERO adjustment is done to get 4mA at the output. Similarly it is set to 119.4Ω, corresponding to 50^oC, and SPAN adjustment is done to get 20mA at the output. Similarly the other temperature transmitter circuits are calibrated.

B. Relative humidity measurement

Measurement of relative humidity in the field plays an important role during the harvesting of the seeds [15]. So this facility is also included in the designed system.

1) Measurement Technique

Psychrometry is the best-suited technique for measuring relative humidity particularly in process industries, which call for rugged and continuous operation [16]. The accuracy of the dry and wet bulb sensors, the maintenance of a minimum ventilation speed, and a clean wick are the major factors that affect the measurement of the relative humidity. When the wick of the psychrometer becomes hard, the bulb will not be thoroughly wet and inaccurate readings will result. Care should be taken to keep the wick clean. It should not be handled unless the fingers are perfectly clean. Distilled water should be used for keeping the wick wet. Accuracy with the fixed position psychrometers can be obtained only by creating free circulation of ambient air around the bulbs. Since relative humidity depends on more than one parameter, multiple regression method is used to derive the relationship. Again by dividing the operating range into three zones, viz. 0^oC - $l0^oC$, 11^oC - 20°C and 21°C – 50°C and then by using the MATLAB and Simulink software package, second order equations are developed for the entire range of temperature 0^oC - 50°C to get the desired accuracy of about ± % in the RH measurement. The equation for the temperature range of 0^oC to 10°C is :

$$RH = 97.4056 - 15.4898\, T_d + 16.2592\, T_w + 0.2317\, T_d^2 - 0.2972\, T_w^2 \qquad (1)$$

The equation for range the 11°C to 20°C is:

$$RH = 93.0129 - 12.6491\, T_d + 13.4314\, T_w + 0.1229\, T_d^2 - 0.1485\, T_w^2 \qquad (2)$$

The equation for the temperature range of 21°C -50°C is:

$$RH = 91.0058 - 9.0872\, T_d + 9.5597\, T_w + 0.0471\, T_d^2 - 0.0540\, T_w^2 \qquad (3)$$

where, T_d – dry bulb temperature and T_w – wet bulb temperature.

2) Dry and wet bulb temperature transmitter

The dry and wet bulb temperature transmitter is implemented using the PT100 Resistance Temperature Detector (RTD) sensors [17]. A mechanism of a water container for keeping the wet bulb wet, by covering the corresponding RTD with one end of a wick and keeping the other end of the wick in the water tank is incorporated. At least half of the length of the wick remains dipped in the water. Similarly a fan mechanism is provided for getting the required airflow around the wet RTD. Circuits using XTR 103 are implemented for measuring the two temperatures. Each circuit takes RTD as input and provides 4-20mA output corresponding to the measuring range of 0-50°C. The XTR-103 has built-in provisions for RTD current excitation, signal amplification and liberalization on a single integrated circuit. Two similar circuits, based on XTR-103, are implemented for measuring the dry and wet temperatures. The zero and span adjustment are carried out to get 4-20mA output signals for a working temperature range of 0-50°C. These two 4-20mA current signals are interfaced to the ADC input port of the micro controller card for further processing.

C. Wireless communication

For wireless communication RS 232 based DIGI's X-Bee–PRO 802.15.4 transceiver module having OQPSK based modulation is used. The operating temperature is –40 ^{o}C to 85^{o}C and the power down current is less than 6mA. It can transmit data up to 1 mile for outdoors range (LOS) and 100m in indoor range at frequency 2.4GHz .The receiver sensitivity is - 100dBm. For every 6dB gain in TX power or RX sensitivity the range of wireless link doubles. For wireless communication, location is also an important issue. Therefore, the module has been tested at different distances and different baud rates inside and outside office to analyze the effect of obstacles in line of sight (LOS) up to 300m. The baud rate error was 0.16%, which is obtained from the calculated and desired baud values at 16MHz [18]. A serial RS-232 and wireless interface is provided to communicate with a host system for remote/ automated monitoring. The signal loss and power received have been calculated at different distances by using (4) and (5). We are procuring the portable RF power meter from Keithley (Model 3500) for measurement of actual power loss.

The signal loss is given by-

$$L\ (dB) = -20 \log_{10} (\lambda / 4\Pi d). \quad (4)$$

where – L = signal loss in free space (dB) and d = distance (meters)

The power received at receiver is given by-

$$P_r = (P_t\ G_r\ G_t\ \lambda_2) / ((4\Pi)2\ d_2\ L) \quad (5)$$

where – Pt = transmitted power = 100mW and G_r & G_t = antenna gain at receiver and transmitter = 2.1dB.

D. *Distance measurement*

For testing of information loss at different places two wireless modules are used. One module is connected to the system through RS232 port placed in a test room and another wireless module is connected with a laptop to check the loss at different places. To calculate line of sight distances between two places, help has been taken from Google Earth. Google Earth maps the Earth by superimposition of images obtained from satellite imagery, aerial photography and GIS 3D globe which can be downloaded free. It provides facility to calculate distance between two selected objects under the Tool option by selecting the ruler. Thus we have located our CEERI office area at Pilani, Rajasthan through Google Earth and then calculated approximate distance in meters between two locations in outdoor ranges. For indoor ranges the distance between two rooms are calculated approximately using Pythagoras theorem on first floor and ground floor.

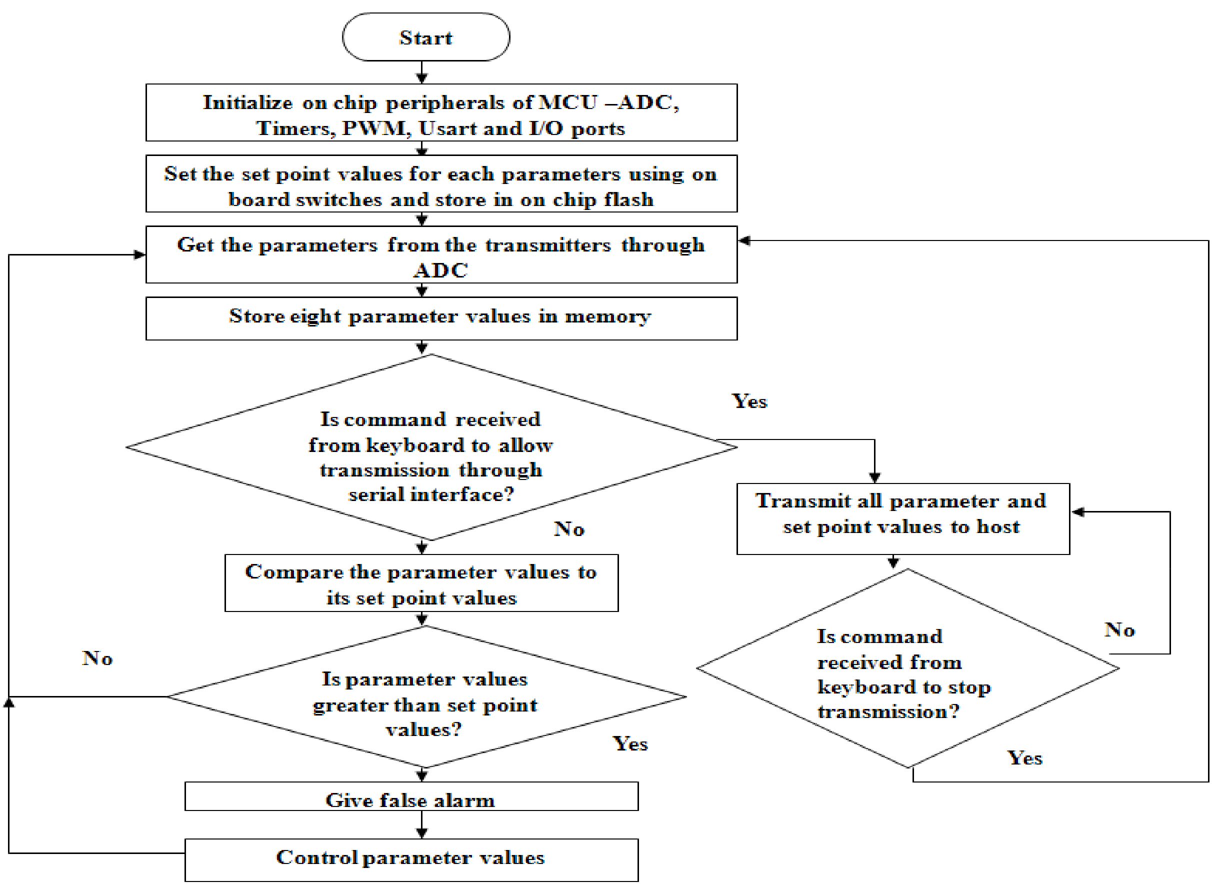

Figure 4. Software Flow of Multi-Sensor Embedded System.

IV. System Software

The embedded software to operate the wireless multi-sensor system is implemented. Subroutine modules for sensor signal digitization, motor control, LCD, keypad, wireless data acquisition and transmission & field tracking algorithm are developed in C language and compiled with MP-LAB C18 cross compiler. The hex file is then ported to the flash memory of the PIC18F452 using PIC programmer. The operation of the software for multi-sensor embedded system is shown in the flowchart in figure 4.

V. Experimental results

Figure 5 shows the experimental setup for testing of the developed system. The developed module is interfaced with temperature sensors through transmitters giving 4 to 20mA current outputs. The wireless module is connected through RS232 interface. The device is programmed using MPLAB IDE programmer. Figure 6 shows the results of the temperature measurement conducted by keeping the temperature sensors in the environmental chamber where programmable temperature setting is done for specified temperature. The temperature measurement results are verified and found to be +/- 1% as tabulated in table I over a span of 100 to 120^{o}C. The variation of calculated signal loss and received power against distance for testing wireless modules are shown in figure 7 and figure 8 measured at various aerial distances with different baud rates.

The RH is calculated from measured dry and wet bulb temperatures and the (1) - (3), and is compared with the expected value from the psychometric chart. The results are given in the following tables II, III and IV respectively.

Since, wireless communication works by creating electromagnetic waves at a source and being able to pick up those electromagnetic waves at a particular destination [14]. During the propagation, some attenuation of the signal takes place due to properties of the transmission medium (air) and obstacles and power density decreases at receiving end. Figure 7 shows this attenuation as a function of the distance between the transmitter and receiver and figure 8 shows the power received at receiver end decreases with increasing the distance between transmitter and receiver locations. The information loss in wireless data communication using the ZIGBEE wireless modules is shown in table V and table VI at outdoor and indoor distance range with and without obstacles.

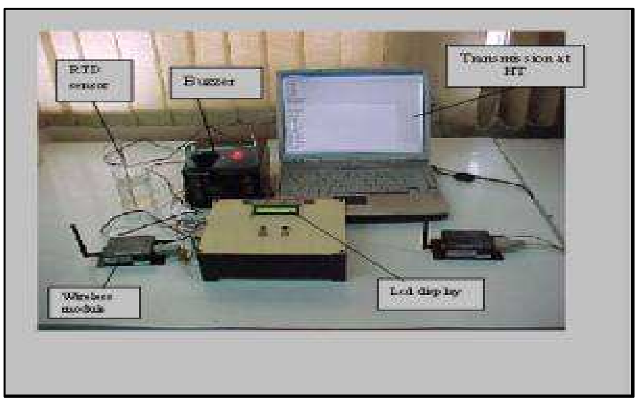

Figure 6. Experimental setup.

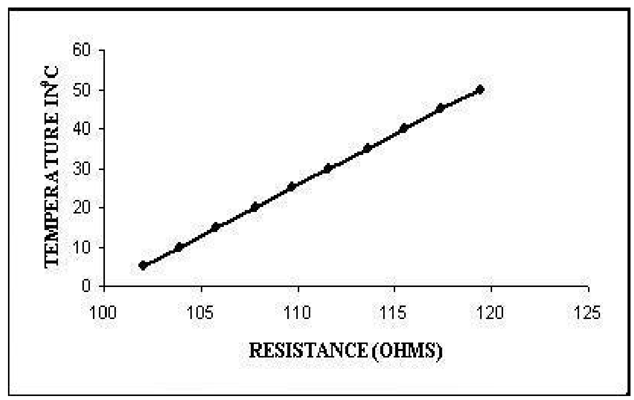

Figure 5. Temperature measurement.

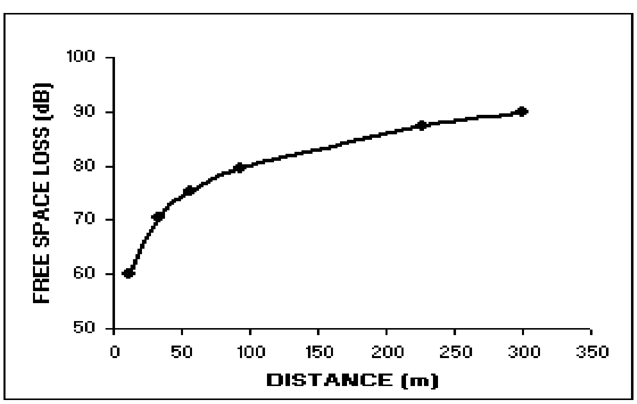

Figure 7. Signal loss.

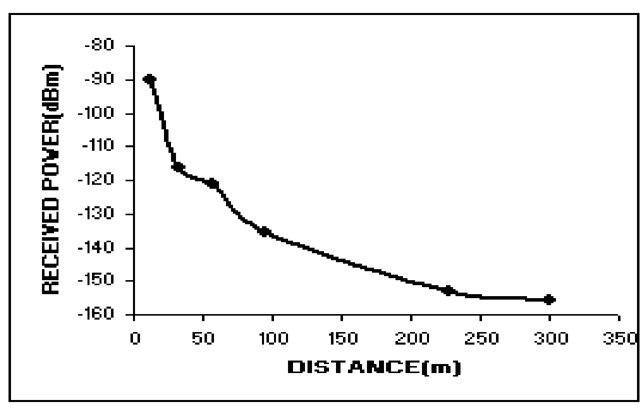

Figure 8. Received power.

TABLE I. TEMPERATURE MEASUREMENT

Resistance (Ohms)	Temperature from Chart(Deg Cen.)	Measured Temperature (Deg Cen)
102.0	5	5.2
103.9	10	10.1
105.8	15	15.0
107.8	20	20.0
109.7	25	25.1
111.6	30	30.1
113.6	35	35.0
115.5	40	40.2
117.4	45	45.1
119.4	50	50.1

TABLE II. COMPARISON BETWEEN MEASURED AND HCART RH VALUES FOR 0-10^{O}C RANGE

Dry Blub Temperature	Wet Bulb Temperature	Measure RH value	RH Value from Psychrometry Chart	Difference between Measured and Chart Values	Percentage Error
2	1.5	91.0728	92	-0.9272	-1.0078
2	1	83.3147	83	0.3147	0.3792
4	3.5	92.4198	93	0.5802	-0.6239
4	3	85.2560	85	0.0256	0.3012
6	5.5	93.2426	94	-0.7574	-0.8057
6	3	58.9099	60	-1.0901	-1.8168
8	7.5	93.5412	94	-0.4588	-0.4881
8	5	62.1805	62	0.1805	0.2911
10	9.5	93.3157	94	-0.0684	-0.7280
10	6.5	58.8034	60	-1.1966	-1.9943

TABLE III. COMPARISON BETWEEN MEASURED AND CHART RH VALUES FOR IO-20°C RANGE

Dry Blub Temperature	Wet Bulb Temperature	Measure RH value	RH Value from Psychrometry Chart	Difference between Measured and Chart Values	Percentage Error
10	9.5	93.0144	94	-0.9856	-1.0485
10	6.5	59.8460	60	-0.1540	-0.2567
12	11.5	93.7525	94	-0.2475	-0.2633
12	11.0	88.7069	89	-0.2931	-0.3293
14	13.5	94.2862	95	-0.7138	-0.7514
14	13.0	89.5375	90	-0.4625	-0.5139
16	12.5	66.7915	67	-0.2085	-0.3112
16	12.0	61.8943	62	-0.1057	-0.1705
18	17.5	94.7409	95	-0.2591	-0.2727
18	17.0	90.5860	90	0.5860	0.6511
20	16.0	66.0971	66	0.0971	0.1471
20	15.5	61.7195	62	-0.2805	-0.4524

TABLE IV. COMPARISON BETWEEN MEASURED AND CHART RH VALUES FOR 20-50°C RANGE

Dry Blub Temperature	Wet Bulb Temperature	Measure RH value	RH Value from Psychrometry Chart	Difference between Measured and Chart Values	Percentage Error
20	19.50	93.9807	96	-2.0193	-2.1034
20	15.50	63.3039	62	1.3039	2.1031
22	21.50	94.4538	96	-1.5462	-1.6106
24	19.00	62.1831	63	-0.8169	-1.2967
26	25.50	95.2343	96	-0.7657	-0.7976
28	26.00	85.5367	85	0.5367	0.6314
30	29.50	95.7938	96	-0.2062	-0.2148

32	30.00	86.6340	86	0.6340	0.7372
34	32.00	87.0997	87	0.0997	0.1146
36	30.00	63.0991	64	-0.9009	-1.4077
38	31.00	58.1618	60	-1.8382	-3.0637
40	39.50	96.2262	97	-0.7738	-0.7977
40	33.00	59.5422	61	-1.4578	-2.3898
42	41.50	96.1469	97	-0.8531	-0.8795
44	37.00	62.1372	63	-0.8628	-1.3695
46	45.50	95.8228	97	-1.1772	-1.2136
46	45.00	93.4871	94	-0.5129	-0.5456
48	47.50	95.5779	97	-1.4221	-1.4661
50	42.00	60.6471	62	-1.3529	-2.1821

TABLE V. INFORMATION LOSS – INDOOR RANGE

S.N.	Baud rate (bps)	Baud rate error (%)	Distance (m) with obstacles	Distance (m) without obstacles	Information loss (Yes/No)
1	1200	0.16	-	<50	No
			57	-	Yes
			64	-	
			-	227	No
2	9600	0.16	-	<50	No
			57	-	Yes
			64	-	
			-	227	No
3	19200	0.16	57		Yes
			64		
				227	No

TABLE VI. INFORMATION LOSS – OUTDOOR RANGE

S.N.	Baud rate (bps)	Baud rate error (%)	Distance (m)	Information loss (Yes/No)
1	1200	+0.16	<20	No
			33	Yes
			57	
			61	
2	9600	+0.16	<20	No
			33	Yes
			57	
			61	
3	19200	+0.16	<20	No
			33	Yes
			57	
			61	

The developed multi-sensor embedded system is also tested on the mobile robotic platform in the field of an area 5m x 5m. The system is tested with LM 335 and RTD temperature sensors for temperature and humidity measurement of soil in the farm over a wireless connectivity. The observed trajectory of the wireless robot in the tested field of 5mx5m area is as shown in figure 9.

VI. CONCLUSION AND FUTURE WORK

A development of the multi sensor embedded system for measuring up to eight sensor parameters optimized by appropriate algorithms with its various features are presented. The test results of the developed prototype system with RTD temperature sensors for temperature measurement over a wireless connectivity for various distances are presented. From the results it can be concluded that for better transmission of signals via wireless communication, the low frequency range along with low baud rate and line of sight range is required to minimize the signal loss. The developed system is cost effective, versatile, and based on generic platform. Currently, efforts are going on to increase measurements up to 16 sensors channels, which are suitable for most of our current applications like RO water purification Plant automation and Smart pond fish management system, where in up to 15 parameters are to be monitored. Also implementation of appropriate wireless reconfigurable sensor network for future perspective so as to make the developed embedded system more applicable in Agro based Industrial applications such as grain and fruit, storage, vegetable storage smart pond automation for fresh aquaculture and so on.

The developed multi-sensor embedded system on mobile robot is also successfully tested to monitor the soil parameters in the farm and transmit the data to the central system using wireless protocol for precision agriculture. Considering the high cost and complexity of number of wireless sensing network systems in agriculture, the proposed system is low power and cost effective with less number of sensors and wireless nodes. Although the experimental conditions were limited, but the preliminary results are promising and shows that the wireless multi-sensing system can be utilized for farm application in precision agriculture.

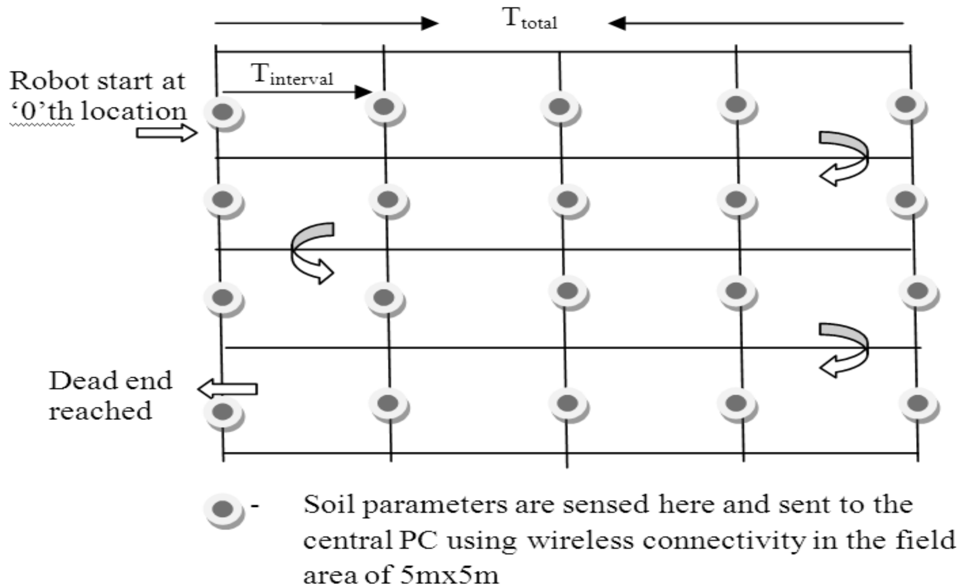

Figure 9. Trajectory of the Wireless Mobile Robot sensing soil parameter.

Acknowledgment

The authors are thankful to Dr. Chandra Shekhar, Director CEERI and guidance. Thanks are due to Mr. A. P. Sharma, Mr. Pankaj Kumar and Mr. Ravi Chaudhary for their help and support for the work.

References

[1] Chandani Anand, Shashikant Sadistap, Satish Bindal and K. S. N. Rao, "Multi -Sensor Embedded System for Agro-Industrial Applications", Proc. 3rd IEEE conference ICN 2008, pp. 94-99, 2009.

[2] H. Ramamurthy, B. S. Prabhu, R. Gadh and A. M. Madni, "Wireless Industrial Monitoring and Control using a Smart Sensor Platform" IEEE sensors journal, vol. 7, no. 5, pp. 611-618 2007.

[3] N. Wang, N. Zhang and M. Wang, "Wireless sensors in agriculture and food industry—Recent development and future perspective", Journal of Computers and Electronics in Agriculture, vol. 50, pp. 1–14, 2006.

[4] B. A. Botre, Ganji Manu, P. Shashank Reddy and S. S. Sadistap, "Development of Mobile Embedded System for Farm Sensing", Journal of Instrument Society of Inda, vol. 40, no. 1, pp 4-7, India, 2010.

[5] IEEE Standard for a Smart Transducer Interface for Sensors and Actuators- IEEE 1451.3 edition, 2004.

[6] L. Liang, L. Huang, X. Jiang and Y. Yao, "Design and implementation of wireless Smart-home sensor network based on ZigBee protocol", Proc. of IEEE International conference on communication, circuits and systems, (ICCCAS-2008), pp. 434-439, 2008.

[7] S. S. Sadistap, Y.K Jain, L. Narayan and S. Devi, "Smart sensor development for CO sensor", Proc. National conference on Instrumentation, (NSI 32), Tamil Nadu, 2002.

[8] R. Vrba, O. Sajdl and M. Sveda, "Smart sensor in wireless network system", Proc. of IEEE 3rd International conference on Information and Communications Technology, pp. 23-33, 2005.

[9] R. Behnke, F. Golatowski, K. Thurow, and D. Timmermann, "Wireless sensor networks for life science automation", In International Forum Life Science Automation, 2007.

[10] J. M. Kahn, R. H. Katz, and K. S. J. Pister. "Mobile Networking for Smart Dust", Proc. of ACM/IEEE International Conference on Mobile Computing and Networking, (MOBICOM-99), March 1999.

[11] www.smartsensors.com

[12] Blackmore, S., "Precision Farming: An Introduction", Outlook on Agriculture, vol. 23, no. 4, pp. 275-280, 1994.

[13] A. Mason, N. Yazdi and A. V. Chavan "A generic multi-element micro-system for portable wireless applications" Proceedings of the IEEE, vol. 86, no. 8, pp. 1733 – 1746, 1998.

[14] B. A. Botre, S. B. Waphare, D. Shirke, D. C. Gharpure, and A. D. Shaligram, "Mobile Odor Tracking Robot Based On Embedded Technology", Proc. IEEE International conference Emerging Trends in Electronic and Photonic Devices & Systems (ELECTRO-2009), Varanasi, pp. 111-114, 2009.

[15] V. Sai Krishana, S. S. Sadistap, Bhanu Prasad and Pawan Kapur, "Microcontroller based relative humidity meter", Journal of Instrument Society of India, vol. 35, No. 4, pp. 350-356, 2003

[16] L. R. Adams, and M. K. Pritchard, "A low-cost microcomputer system for controlling relative humidity in horticultural storages", Hort Technology, vol. 4, no.1, pp. 51-54, 1994.

[17] P. Kapur, P. Bhanu Prasad, M. Singh, B. Das, M. P. Kaushik, and K. K. Pandey, "PC based Systems for Composting and Cropping Stages of Mushroom Cultivation", IETE Technical Review, vol. 20, no.3, pp. 241-249, 2003.

[18] Technical data manual PIC18F452, available online, pp. 185-188.