

Prototype System for Monitoring and Computing Greenhouse gases

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Abstract—Global warming is not only the problem of the government or individual organization it is the fundamental problem of every individual. The main cause for global warming is green house gases (GHG). Monitoring and computing the greenhouse gases are a major challenging work. Globally, over the past several decades, human-induced activities like industrial revolution and burning of fossil fuels in power stations, vehicle transport systems and industries contribute significantly to the emission and concentration of GHG in atmosphere. Avoiding their usage may reduce the emission of GHG, but it may not be a practical approach as they are mandatory in modern day-to-day life, alternatively regular monitoring and reporting of GHG parameters may create awareness to individuals and organization for effective and proper use of human induced activities. There are very few works done in developing embedded systems for computing GHG. We have implemented a prototype system for sensing and computing the level of existence of GHG parameters (like CO₂, CO, temperature and humidity) in atmosphere using environmental sensors and advanced microcontrollers and energy efficient wireless technologies. The Prototype supports quality in terms of low cost, energy efficiency, flexibility and user friendliness. Data is collected, consistency models are define for analyzing the quality of data and the level of GHG in the deployed environment is computed. The results show that the prototype is capable for monitoring and computation of GHG in the deployed environment and can be applied at all levels of organization for creating awareness, performing scientific studies and to forecast remediation policies by the authorities to individuals and organization in controlling GHG parameters.

Keywords- Wireless sensor network; greenhouse gases; parts per million.

I. INTRODUCTION

Overwhelming majority of scientist agree that the globe is undergoing major climate change due to increase in greenhouse gas (GHG) concentration in atmosphere. GHG in atmosphere absorb and emit radiations within thermal infra-red range. This process is fundamental cause for global warming. One of the main causes of global warming is increase in level of emission of Carbon dioxide. Primary sources for emission of green house gases are burning of fossil fuels in power plants, vehicle transport and industrialization. The effects of global warming bring dangerous weather patterns which may cause unstable agriculture and economy [12][13][21][23][24]. Therefore, it is a great important to monitor and compute greenhouse gases in atmosphere, where we live and work. Proper monitoring may help in finding root cause of emission and also facilitates the authorities in decision making for controlling GHG parameter [25-31].

Previously wired transmission mode is used to connect sensors with PC, which could cause large cost, wiring complexity and difficulty in maintenance of traditional environment monitoring system. In recent years, monitoring

systems using wireless sensors technology has become more important because wireless sensor network (WSN) is very suitable for distributed data collecting and monitoring in tough environments. Recently monitoring system based on wireless sensor technology using ZigBee, RFID, GSM/GPRS and short message service (SMS) wireless communication system are proposed [1-8]. We use ARM microcontroller for easy programming, flexible interfacing and XBee wireless module for power efficient communication.

In this paper we present a embedded system design for monitoring and computing greenhouse gases in a wireless personal area network (WPAN). The prototype supports quality in terms of easy programming, flexible interfacing, low cost, energy efficiency and user friendliness. The primary components in the prototype include carbon dioxide sensor, carbon monoxide sensor, temperature sensor, humidity Sensor, ARM Micro controller and XBee Pro Wireless module. The system performs data acquisition using client server technology and graphs are plotted for performing analysis, scientific studies and to forecast remediation policies to authorities in controlling greenhouse gases. The results show

that the prototype is capable to monitor and compute GHG in the deployed environment and can be applied at all level of organization as a preliminary effort in controlling global warming.

II. BACKGROUND KNOWLEDGE

Global Warming has been identified as one of the greatest challenges facing nations, governments, business and citizens over future decades. Climate change has implications for both human and natural systems and could lead to significant changes in resources use, production and economic activity [13]. The increase in concentration of GHG in earth atmosphere contributes significantly to global warming. In response, initiatives are necessary to limit GHG concentration in atmosphere [14]. Such initiatives rely on the quantification, monitoring, reporting and verification of GHG emissions and removals [27].

A. Greenhouse gas

Gases that trap heat in atmosphere are often called greenhouse gases (GHG). The primary GHG include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), Sulfur hexafluoride (SF_6) and water vapor (H_2O). GHG constituent of atmosphere, both natural and anthropogenic, absorbs and emits radiation at specific wavelength within spectrum on infrared radiation emitted by earth surface, atmosphere, and clouds. This process is the fundamental cause for global warming [23] [25]. Due to global warming average temperature of earth surface increased by $0.74 \pm 0.18^\circ\text{C}$ ($1.33 \pm 0.32^\circ\text{F}$) during the 20th century and likely to rise further, 1.1 to 6.4°C (2.0 to 11.5°F) during the 21st century [12][13].

B. Global Warming Potential

Global warming potential (GWP) is a relative measure of heat trapped by GHG in atmosphere. GWP is based on radiative forcing properties, including radiative efficiency (infrared absorbing ability) and decay rate of each gas relative to carbon dioxide. Radiative forcing believed to influence the climate system and the global warming potential can be used to estimate the impacts of emission of different gases upon the climate system [12].

TABLE I. RADIATIVE FORCING OF GHG

Gas	Mole Fraction Changes		Radiative Forcing (WM^{-2})	
	2005	1998	2005	1998
Carbon dioxide	379 $\mu\text{mol/mol}$	365 $\mu\text{mol/mol}$	1.66	1.46
Methane	1,774 nmol/mol	1,745 nmol/mol	0.48	-
Nitrous oxide	319 nmol/mol	314 nmol/mol	0.16	0.15
Chlorofluorocarbon	538 pmol/mol	533 pmol/mol	0.17	0.17
Sulfur hexafluoride	5.6 pmol/mol	4.2 pmol/mol	0.002	0.002

Table has its source in Inter governmental panel on climate change (IPCC) Fourth Assessment Report, 2007, Chapter 2. The report describes warming and cooling effects on planet in terms of radiative forcing. Mole fraction

Unit : $\mu\text{mol/mol} = \text{ppm} = \text{parts per million (10}^6)$; $\text{nmol/mol} = \text{ppb} = \text{parts per billion (10}^9)$; $\text{pmol/mol} = \text{ppt} = \text{parts per trillion (10}^{12})$.

Radiative forcing capacity (RF) is the amount of energy per unit area, per unit time, absorbed by GHG that would be otherwise lost to space. GWP is defined as ratio of time integrated radiative forcing of pulse emission of 1 kg of some component i relative to that of 1 kg of reference gas (CO_2).

$$RF = \sum_{n=1}^{100} Abs_i * F_i / (\text{pathlength} * \text{density}) \quad (1)$$

Where subscript i represent an interval of 10 inverse centimeters. Abs_i represents integrated infrared absorbance of the sample in that interval, and F_i represents RF for that interval. Global Warming potential (GWP) is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1kg of a reference gas.

$$GWP_i \equiv \frac{\int_0^{TH} RF_i(t)dt}{\int_0^{TH} RF_r(t)dt} = \frac{\int_0^{TH} a_i \cdot [C_i(t)]dt}{\int_0^{TH} a_r \cdot [C_r(t)]dt} \quad (2)$$

Where GWP_i is Global Warming potential of component i , TH is time horizon over which the calculation is considered, RF_i is global mean RF of component i , a_i is RF per unit mass increase in atmospheric abundance of component i , $C_i(t)$ is time dependent abundance of i , and corresponding quantities for reference gas (r) in denominator. The numerator and denominator are called absolute global warming potential of i and r respectively [21].

C. Related Work

Environmental monitoring using wireless sensors technology has become more important because wireless sensors technology is very suitable for distributed data collecting and monitoring in tough environments (Hui Liu et al., 2007). Previously wired transmission mode is used to connect sensors with PC, which could cause large cost, wiring complexity and difficulty in maintenance. The advantages of wireless transmission are significant reduction and simplification in wiring and harness, allow faster deployment and installation of various types of sensors integrated with computing and communication units to form nodes with extremely low cost, small size and low power requirement [33].

Previous research on developing of wireless sensor monitoring system focus on reducing the electricity cost by designing low power consumption node for monitoring application. Seung Chul Lee et al. (2007) designed an indoor air-conditioning system with ad-hoc query function for wireless sensor network platform and the proposed electrochemical sensor has lower power consumption than semiconductor gas sensor and able to measure CO gas and the temperature of indoor air-state and transfer the data wirelessly

by using ad-hoc network. Andrzej et al. (2009) proposed architecture and application of ZigBee-based mesh network combine with event-based control technique and found that the architecture shows low power consumption of the node for the application in the average of $17.4\mu A$, while event-based control reduced the number of changes by more than 80% in comparison with a traditional time-based controller. Xiliang Zhang et al. (2008) achieved measurement and control with lower power, lower cost and lower latency by using improved LEACH clustering algorithm as a tool for analyzing latency and energy consumption for three-level network model of the wireless monitoring and control system based on multi-span architecture.

In recent years researchers on wireless sensor monitoring system discussed on wireless technologies being developed range from simple IrDA that uses infrared light for short-range point-to-point communications to wireless personal area network (WPAN) for short range, point-to multi-point communications, such as Bluetooth and ZigBee, to mid-range, multi hop wireless local area network (WLAN), to long-distance cellular phone systems, such as GSM/GPRS and CDMA (Ning Wang et al., 2006). Hui Liu et al., (2007) discussed short message service (SMS) as an effective and economical solution of communication in wireless sensor network. A prototype mobile augmented real system is designed for visualizing 3D as well as textual representations of environmental information in real-time using a lightweight handheld computer (Daniel goldsmith et al., 2008). Jong Won Kwon et al. (2007), Han Zhigangn et al. (2009) implemented air pollution monitoring system using ZigBee technologies and embedded system. Greenhouse temperature and humidity monitoring system was build using zigbee wireless sensor network technology and experiment shows that the system operates stably and the energy consumption was 22.4 mA at work, 4.7 mA in sleep and the success rate of data packet reception was 97.1 % (Guomin He et al 2010). Consistency model are key to evaluate the quality of data, many consistency models have been proposed for distributed and collaborative systems; however it is not applicable to WSN because of its limited resource constraints. Kewei sha et al. (2008) implemented consistency model for WSN and it may not applicable to our prototype because of its distinct features such as limited resource constraints, specific characteristics of the application. Hence a novel consistency model should be remodeled to evaluate the quality and dependability of the collected data.

Different from the above approaches, we present a embedded system prototype for wireless sensor network application for monitoring and computing GHG parameters using environmental sensors, advanced computing machine and energy efficient wireless module. The prototype architecture supports quality in terms of easy programming, flexible interfacing, low cost, energy efficiency and user friendliness for a distributed data acquisition in a wireless personal area network. The prototype supports in system serial programming with extensive debug facilities: on-chip JTAG interface unit, embedded ICR-RT real time debug unit. Consistency models are defined for evaluating data quality.

III. SYSTEM OVERVIEW

The system components include carbon dioxide sensor, carbon monoxide sensor, temperature sensor, humidity sensor, ARM micro controller and XBee pro wireless module. Figure 1 shows the overview of the components used in the system prototype.

A. Metadata for Sensor

- MG-811 sensor has high sensitivity to carbon dioxide (CO_2). The gas sensor can measure the concentration of CO_2 up to 10000 parts per million (PPM).
- MQ-7 sensor has high sensitivity to carbon monoxide (CO). The gas sensor can measure the concentration of CO up to 10000 PPM
- LM 35 sensor can measure temperature in the range between -55 to +155 degree Celsius
- Sy-Sh-220 sensor can measure relative humidity percentage (%RH)

B. Metadata for ARM Microcontroller

- 32-bit micro controller with USB 2.0 module, Universal Asynchronous Receiver Transmitter (UART) Module, faster I/O ports, pipe lining techniques, timer / counter module, watch dog timer and system control
- 512 KB flash memory, 40 KB static Memory
- 400 K bit/s data rate
- Supports devices of heterogeneous nature

C. Metadata for XBee PRO

- ISM 2.4 GHz frequency band
- Direct Sequence Spread Spectrum
- 250 kbps data rate
- pin-for-pin compatible
- IEEE 802.15.4 networking protocol
- Two or three times the range of standard ZigBee
- Receiver sensitivity -100dBm (1% packet error rate)
- Supported network topologies: Point-to-point, Point-to-multipoint & peer-to-peer
- 12 Direct sequence channels

Figure 1 shows the architecture of system prototype which includes sensing unit and base station (sink). The sensing unit components include: sensors for environmental parameters, ARM microcontroller for computation and temporary storing and XBee Pro for transmitting the data to base station. The system is experimented using two sensing unit and a base station. The base station component include: Xbee Pro for receiving the data from sensing unit and the data table is created for analysis. The system is powered by 5V/ 2A using SMBS. All the components used in the system are cost effective and the prototype supports interfacing of components which are heterogeneous in nature and supports energy efficient modes for operation.

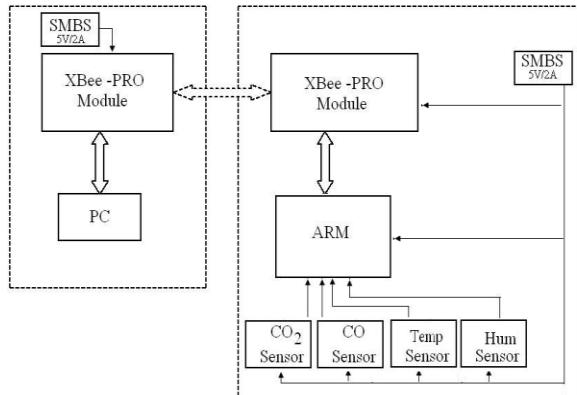


Figure 1. System Prototype Architecture

The prototype confirms to two key functionalities: *data gathering* (i.e. many-to-one communication between sensing units and base station) and *data dissemination* (i.e. one-to-many communication between base station and sensing units). The general data format for the prototype is defined as follow.

$$(p_i, Seq, T, Val)$$

Where p_i denotes the data is from the i^{th} sensor for parameter p ; Seq is the sequence number of the sampled value of the i^{th} sensor for parameter p ; T_{Sample} is the time when the value is sampled. Val is the value of the reading for the parameter p . In our application prototype the parameters sampled are CO_2 , CO , temperature and humidity. The system samples data at regular time interval and operates in five modes: *Ideal mode*, *Transmit mode*, *Receive mode*, *Sleep mode*, *Command mode*. When not receiving or transmitting the data the system is in idle mode and power requirement for the mode is 55mA . In transmit mode the system will transmit the sensed data and the power requirement is 250mA . In receive mode the power requirement is 55mA . Sleep modes enable the module to enter states of low-power consumption when not in use and the power requirement is $<50\mu\text{A}$. The communication range of prototype is 90 meter in urban/indoor conditions and 1 mile (1600 meter) for outdoor line-of-sight. In a periodically reporting sensor network, the period of data reporting is named as the collection round .Therefore, the total energy cost of successfully gathering all sensed data in one round is given by

$$E = E^{TM} + E^{RM} + E^{IM} + E^{SM} + E^{CM}, \quad (3)$$

Where E^{TM} is the energy cost for the transmission mode, E^{RM} is the energy cost for receiving mode, E^{IM} is the energy cost for ideal mode, E^{SM} is the energy cost for sleep mode, E^{CM} is the energy cost for command mode respectively. The total energy cost for the sampling period can be calculated as $E_{\text{Total}} = \sum_{i=1}^n E_i$. Where n is the sampling rate. For example,

the sampling rate is 288, if collection round is 5 minutes and sampling period is one day.

IV. PROBLEM ANALYSIS

The quality of data measured and collected by the wireless sensor networks may get affected by its stringent resource constraint, internal and external factors of sensor nodes deployed in harsh and unattended environment, because of which real world data are often dirty. Especially when the sensor node calibration fails, power failure, malicious attacks, noise and other environmental effects which further influence quality of the collected raw data and aggregated results. Given a dirty database D , one needs automated methods to evaluate the quality and dependability of data.

V. EVALUATION ON DATA QUALITY

Quality of data is reflected by the accuracy and timeliness of the data. Consistency models are key to evaluate the quality of collected data and it is viewed in two aspects: *the numerical consistency* which requires that the collected data should be accurate and *the temporal consistency* which means that the data should be delivered to the sink before it is expected. Our applications pay more attention to the temporal consistency. Lot of consistency models have been proposed for distributed and collaborative systems; however it is not applicable to our prototype because of its distinct features such as limited resource constraints, specific characteristics and application. Hence a novel consistency model has been remodeled for evaluate the quality and dependability of the collected data. Based on the application prototype here we model four types of consistency, the *range consistency*, the *replication consistency*, the *data loss consistency* and the *trend consistency*. The range consistency means every value in D is within the range of the consistency semantics. We define it as below.

$$\text{RngCon} = \text{Insemantics}(Val, \varepsilon) \quad (4)$$

Where *Insemantics* judges the numerical consistency by checking all the values in D follow the predefined bound ε for every parameter p . For example the predefined bound for CO_2 parameter is 0-10000 ppm, any value out of the bound is unacceptable and may significantly affect the aggregation of result. The replication consistency checks for replicated values in D . So the replication consistency is modeled as

$$\text{RepCon} = \text{Repsemantics}(\text{Count}(T, p_i, Val) > 1) \quad (5)$$

The consistency is judged by counting D for the replicated values of the parameter p in a time T . For example if the collected data contains multiple values for the parameter CO_2 in a time T , than it may lead to confusion and can affect the mean of the parameter. The loss consistency checks for sampled data missed during transmission. We define it as below,

$$\text{LosCon} = \text{Losemantics}(\text{Count}(D) \geq \text{Sample}_{\text{rate}}) \quad (6)$$

Where, *Losemantics* judges the loss consistency by checking the count of D is not less than the estimated sampling rate, i.e., sampled value for the parameter p in a Time T should be > 0 . The Trend consistency detects whether the trend of collected data is maintained, i.e., By detecting and counting any two

continuously sampled data value val_i and val_{i+1} which are out of each other's endurance range (3). Trend consistency is modeled as follows,

$$TrndCon = (TrndSatisfy(D, \alpha)) \quad (7)$$

The consistency models will be applied to every sensed data for evaluating the quality. Results will be helpful for application scientist in evaluating the consistency and dependability on the data.

VI. CONCLUSION

We present an embedded system design of wireless sensor monitoring system for sensing and computation of global warming indicators. Four commercial sensors had been integrated with ARM processor to monitor and compute the level of existence of GHG parameters (like CO_2 , CO temperature and humidity) in atmosphere using information and communication technologies. Prototype operates for data gathering and data dissemination using five modes and preliminary test prove that the developed prototype is capable to monitor and compute CO_2 , CO temperature and humidity parameters in the deployed environment and has several advantages in term of low cost, flexibility, user friendliness and energy efficiency. Data is collected and can be applied at all levels of organization for creating awareness, performing scientific studies and to forecast remediation policies by the authorities to individuals and organization in controlling global warming and GHG parameters. We define application specific consistency models for evaluating the data quality of the prototype. This is our initial step in building efficient embedded system for monitoring and computing GHG parameters. We expect this paper will raise the global warming problem to the community.

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APPENDICES

The results collected verified the fact that the rise in concentration of GHG in atmosphere increases temperature. Here we provide sample data and plotted graphs of the prototype system.

TABLE II. SYSTEM PROTOTYPE SAMPLE DATA

S.no	Time	Environmental GHG Parameters			
		CO2 (PPM)	CO (PPM)	Tem (degree Celsius)	Humidity %
1,	14.00	310	90	31	50
2.	14.15	330	80	31.5	30
3	14.30	300	100	29	60
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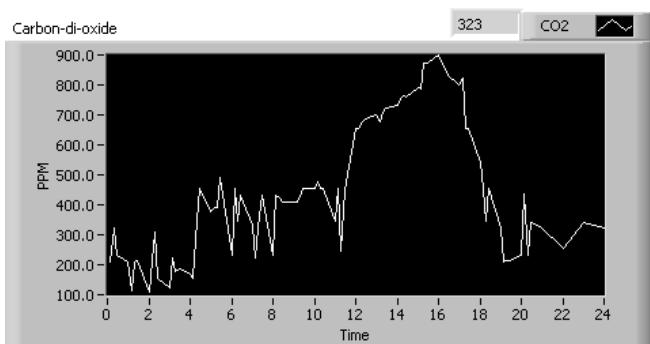


Figure 2. The Change in CO₂ Concentration as Function of Time

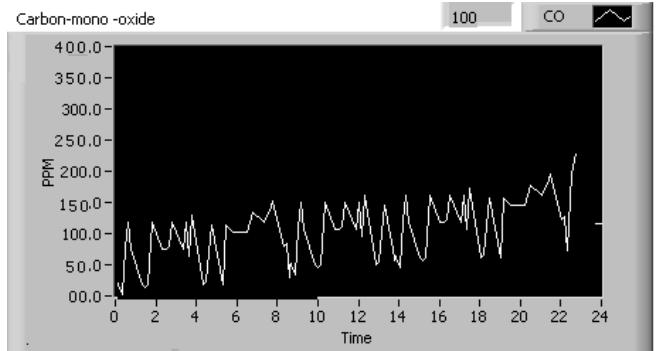


Figure 3. The Change in CO Concentration as Function of Time

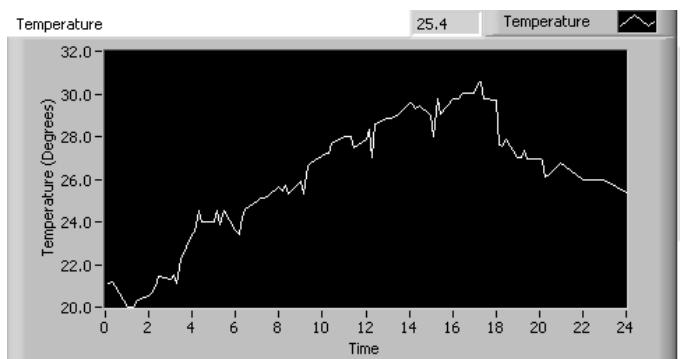


Figure 4. The Change in Temperature as Function of Time

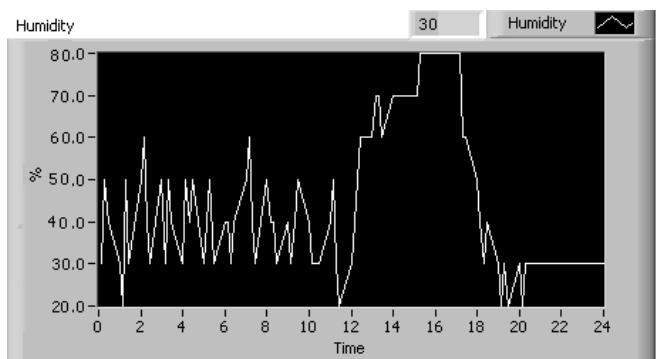


Figure 5. The Change in Humidity as Function of Time

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