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IoT enabled Environmental Monitoring System for Smart Cities

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***Abstract*—A smart city enables the effective utilization of resources and better quality of services to the citizens. To provide services such as air quality management, weather monitoring and automation of homes and buildings in a smart city, the basic parameters are temperature, humidity and CO_2. This paper presents a customised design of an Internet of Things (IoT) enabled environment monitoring system to monitor temperature, humidity and CO_2. In developed system, data is sent from the transmitter node to the receiver node. The data received at the receiver node is monitored and recorded in an excel sheet in a personal computer (PC) through a Graphical User Interface (GUI), made in LabVIEW. An Android application has also been developed through which data is transferred from LabVIEW to a smartphone, for monitoring data remotely. The results and the performance of the proposed system is discussed.**

***Index Terms*—Smart City; Internet of Things; WSN; Android; Carbon Dioxide; Environmental Monitoring**

I. Introduction

The Internet of Things is a network of physical objects that consists of sensors, software and electronics which have the ability to communicate with each other as well as with users. It is rapidly evolving due to the convergence of information and communication technologies and the internet. One of the applications of Internet of Things (IoT) in the urban context is the smart city that promises to improve the quality and performance of urban services by the use of Information and Communications Technology (ICT). It also improves the life style of the citizens by providing better facilities and simultaneously reduces the administrative efforts for management of the city enabling effective utilization of resources and better quality of services.

The services for which quality can be enhanced in a smart city are monitoring the strength of buildings, waste management, air quality management, weather monitoring, noise monitoring, traffic management, parking management, energy consumption management and automation buildings. Temperature, humidity and CO_2 are the basic parameters for services like; (i) air quality management for reduction of pollution and healthy environment [1], (ii) weather monitoring for future agricultural actions and human comfort [2] and (iii) automation of public buildings for reducing human effort and energy consumption [3]. To achieve this a wireless sensor node is required to collect and monitor the data wirelessly.

There have been numerous efforts on microclimate monitoring using Wireless Sensor Network (WSN). The initial efforts of using ICT based technology for microclimate monitoring system that monitors parameters like temperature and humidity on a mobile device in [4] and [5] is discussed. The deployment and networking and routing issues for similar microclimate monitoring systems is discussed in [6]. In [2], [3] and [7] authors report indoor air quality monitoring by measuring pollution levels for indoor environments, the importance of energy consumption and the requirements of very low-power WSNs for microclimate monitoring. In an earlier work, we have developed independently a battery less wireless temperature sensor node for smart building applications in [8] and [9] attaining energy autonomy. By doing so, the problem of replacing batteries, often a cumbersome and expensive process is addressed. More recently, in [1], authors discuss the importance of technologies and architecture for urban IoT and a proof of concept monitoring system for a smart city. This paper discusses our efforts to develop a customised IoT enabled environment monitoring system to monitor important parameters such as temperature, humidity and CO_2. To the best of our knowledge, this is the first effort to monitor environmental parameters within one of the smart cities in Gandhinagar, Gujarat, India.

This paper is organized as follows. Section II presents the architecture of the proposed WSN and the methodology used for data transmission. Section III reports the experimental results derived during the implementation and validation of the presented system, through its deployment. Section IV concludes this paper and provides some prospective on possible future work.

II. System Description

The proposed IoT enabled sensing and monitoring system consists of a transmitter node(TX node) and receiver node(RX node) as shown in Fig 1. The sensed data from the TX node is transmitted to RX node through wireless communication. Finally, the data received at the RX node is transferred to a personal computer (PC) through a USB interface. The sensed data is depicted graphically and recorded in an excel sheet through a customized Graphical User Interface (GUI), which is developed in LabVIEW. This data is then transmitted to a MySQL database via internet. The PHP API execution, on

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internet enables transfer of data from the MySQL database to the android based smart phone, thereby enabling IoT based applications.

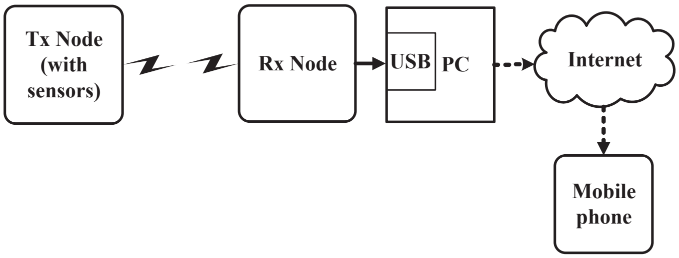

Fig. 1. Architecture of the IoT enabled sensing and monitoring system

A. Node

The proposed IoT enabled sensor node (IoT-SN) consists of a temperature and humidity sensor, CO_2 sensor, an ultra low power μcontroller and a wireless transceiver as shown in Fig 2. The temperature, humidity and CO_2 readings are processed by the μcontroller and transmitted through the wireless transceiver. The receiver node has the same components except the onboard sensors. Data sensing and aggregation on the node can be configured by a customized software code and is dependent on the application. Further to this, a custom voting algorithm is implemented at TX node for data reliability. Power is supplied to the TX node by three AA batteries, while the receiver node attached to a PC is powered through the USB interface.

1) Sensor: The on-board temperature and humidity sensor SHT11 provides a fully calibrated digital output and can be treated as a golden standard [10]. This is also verified with various other standard instruments in laboratory conditions. The analytical equations from the data sheet of the sensor is verified by manipulations. The sensor has an operating range of -40°C to ±123.8°C for temperature and 0 to 100% RH for relative humidity. It has an accuracy of±0.4°C for temperature and ±3% RH for relative humidity, which is useful for many indoor applications and for various outdoor applications such as smart buildings, weather monitoring *etc*. The sensor has an operating voltage range of 2.4 to 5.5 V, that can be used in applications having low power requirements (see Table I). The sensor has very fast response time and typically needs 11 *ms* to be in an active state from the power down state. After each measurement, it automatically switches over to a sleep mode with low current requirements.

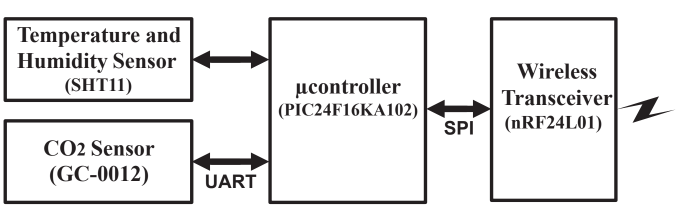

Fig. 2. Proposed Sensor Node

TABLE I
VOLTAGE AND CURRENT OF SENSORS

Module	Voltage	Mode	Current
Sensor (SHT11)	3.3 V	Measuring	0.55-1.0mA
		Sleep	$\sim 0.3\mu A$
Sensor (GC-0012)	3.3 V	Active	$<$ 1.5 mA

The ultra low power COZIR^{TM} CO_2 sensor, GC-0012, from CO_2 Meter [11] is ideally suitable for the battery operated devices. Sensor works on Non-dispersive infrared (NDIR) absorption method, with measurement range of 0 to 10,000 ppm. Sensor has ultra low power consumption of 3.5 mW, with operating voltage range of 3.25 to 5.25 V. It has a average current consumption of less than 1.5 mA as shown in Table I.

2) Microcontroller: The on-board PIC24F16KA102 μcontroller is a 16 bit μcontroller from Microchip, with extreme low power (XLP) technology and consumes *nano*watts of power. It can run on different power management modes such as run, idle, doze, sleep and deep sleep, making it ideal for running low power algorithms for WSN applications. The operating voltage range is from 1.8V to 3.6V. Table II shows the current consumption of the μcontroller for different states of operation [12].

TABLE II
VOLTAGE AND CURRENT OF THE μCONTROLLER

Module	Voltage	Mode	Current
Microcontroller (PIC24F16KA102)	3.3 V	Active@32MHz	11-18 mA
		Deep Sleep	$0.55\mu A$

3) Wireless Transceiver: An ultra low power nRF24L01 from Nordic [13] is used for the radio unit of the proposed IoT-SN. This transceiver can operate from 1.9V to 3.6V at 2.4-2.5 GHz ISM band and interfaces with the μcontroller through a 4-wire, Serial Peripheral Interface (SPI). It has different modes of operation like Transmitter (TX) mode, Receiver (RX) mode, two Standby modes and a Power Down mode. Table III shows the power consumption of each mode of operation, where it can be seen that when the transmitter is not working it should be kept in the power down mode.

TABLE III
VOLTAGE AND CURRENT OF TRANSCEIVER

Module	Voltage	Mode	Current
Transceiver (nRF24L01)	3 V	TX mode (0 dBm)	11.3mA
		RX mode(2Mbps)	12.3mA
		Standby-I mode	$32\mu A$
		Power Down mode	900nA

Also as shown in Fig 3, the transceiver operates in Shock Burst and Enhanced Shock Burst modes. In Enhanced Shock Burst mode, the receiver sends an acknowledgement to the

TABLE IV

DURATION OF DIFFERENT STATES OF THE WIRELESS SENSOR NODE

Modules/States	S1	S2	S3	S4	S5	S6
μcontroller Transceiver SHT11 GC-0012	Sleep Power Down Sleep Sleep	Active Power Down Active Sleep	Active Power Down Sleep Active	Active Power Down Sleep Sleep	S2 to S4 repeated twice	Active Active Sleep Sleep
Time Duration	34 *secs*	400 *ms*	0.11*secs*	1*sec*		235 μs

TABLE V

POWER CALCULATION FOR THE PROPOSED IOT-SN

Modules	S1	S2	S3	S4	S6
	Current (mA) for different states				
Microcontroller	5.4e-4	15.55	15.55	15.55	15.55
Transceiver	1.26e-3	1.26e-3	1.26e-3	1.26e-3	11.3
SHT11	1.3e-5	1.31	1.3e-5	1.3e-5	1.3e-5
GC-0012	-	-	0.68	-	-
Total I (mA)	1.8e-3	16.86	16.23	15.55	26.85
Time (*secs*)	34	0.4	0.11	1	2.35e-4
Repetition of time	1	3	3	2	1
Voltage	3.3	3.3	3.3	3.3	3.3
Energy (mJ)	0.20	66.77	17.67	102.63	0.02
Total Energy (mJ)	=	187.29			
Total Time (sec)	=	37.53			
Average Power (mW)	=	4.99			

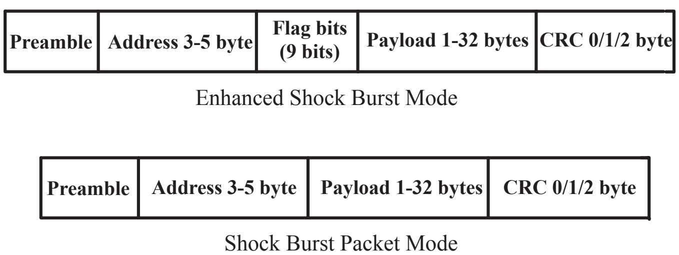

Fig. 3. Transmitting and Receiving Packet Format

transmitter after receiving the data, which enables the detection of data loss. In Shock Burst mode, the preamble and CRC of the data packet is generated automatically. Also, unlike in Enhanced Shock Burst mode, it eliminates the need for 9 flag bits and therefore demands less memory Furthermore, Shock Burst mode allows lower data rate with reduction in average current consumption and therefore it is the preferred mode in our proposed work.

The nRF24L01 can be configured to receive data from as many as the six different transmitters through as many as six different data pipes, each having its own unique address. In the proposed system only one data pipe is sufficient, i.e., pipe-0 for transmission between transmitter and receiver node.

B. Methodology for Sensing and Transmission

The operation of the proposed IoT-SN consists of three phases; (i) sleep (ii) sensing and (ii) transmission. Table IV shows the different states of the individual components. The bottom most row of the table shows the duration of time for which the modules are active in those states. The graphical representation of the states is shown in Fig 4, depicting the time duration and current consumption of the proposed IoT-SN in different states.

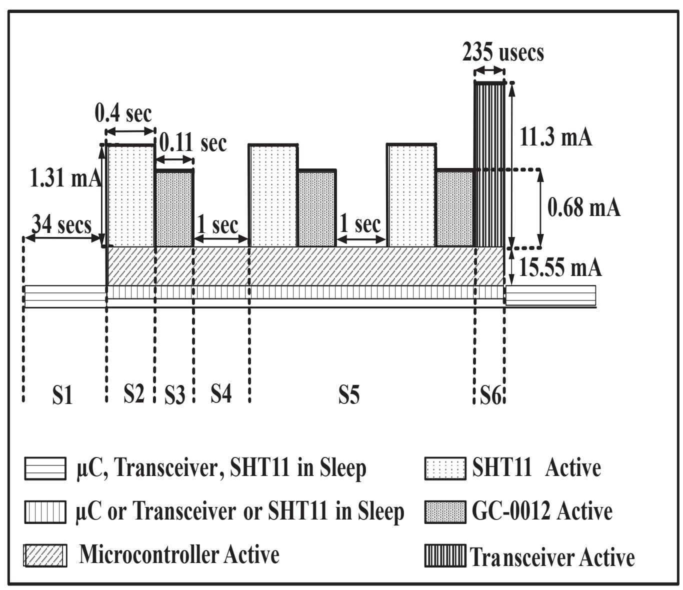

Fig. 4. States (Sensing and Transmission) for the proposed IoT-SN

Initially, switching on the power automatically puts the WSN in state S1, where it stays for 34 *secs*. In state S1 all modules are in sleep state. After S1, it switches to state S2 of duration 0.4 *secs*, in which, SHT11 is setup and data is written to the μcontroller memory. Duration of S3 is 0.11 *secs*, in which GC-0012 is setup and data related to CO_2 is written in microcontroller memory. To keep the heating of SHT11 low, state S4 is kept of 1 *sec*. In state S5, states S2 to S3 are repeated twice at the interval of 1 *sec*. In state S5, after the three sets of data are written to the microcontroller memory, a voting algorithm is performed to remove anomalies, if any. In state S6, nRF24l01 is setup as a transmitter and data is sent to the receiver node. After state S6, S1 to S5 are repeated again. This provides an intuitive representation to optimize the operation of the proposed IoT-SN depending upon the power requirement of the application. For example, enlarging S1 sufficiently will bring down the overall energy of the proposed IoT-SN.

For transmission it is assumed that data from the TX node is sent at every 37.53 *secs*. At the receiver node, after 39 *secs*, it is receiving data at regular intervals. Table V shows the power calculations for the proposed IoT-SN. For different states, total current is calculated by adding currents of all modules, according to their states as stated in Fig 4. For each state, the final value of the time is obtained by multiplication of time and repetition of time. For example, for state S2, final value of time is 0.4 *sec* is multiplied by 3. The total time calculated by summation of final value of time for all states is 37.53 *secs*. Energy for different states is calculated by multiplication of total current, voltage, time and repetition time. Total energy is the summation of energy of all the states of the proposed IoT-SN. The average power is obtained by dividing the total energy (187.29mJ) with the total time period (37.53s) and is found to be 4.99 mw.

C. Graphical User Interface

A graphical panel of GUI made in LabVIEW is developed as shown in Fig 5. The data is displayed in both graphical and numeric form. Virtual Instrument Software Architecture (VISA) API is used to interface sink node with LabVIEW. VISA is a standard I/O API for instrumentation programming. It is a standard for configuring, programming and troubleshooting instrumentation systems comprising GPIB, VXI, PXI, Serial, Ethernet, and/or USB interfaces. VISA is adopted as it is interface independent

The monitored data is stored in sheet with current date and time. In the front panel, user can configure the system setup. The programming is developed in such a way that the excel sheet stores the actual time of sensing instead of delayed time, depending on time data entered in front panel by user.

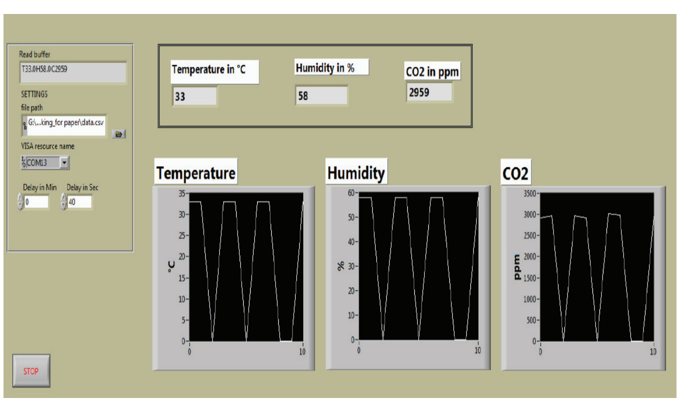

Fig. 5. Graphical User Interface

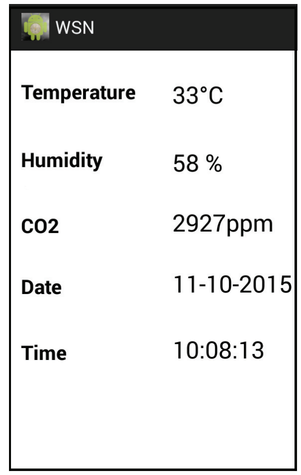

Fig. 6. Android Application

D. Android Application

Further, to enable Internet of Things, the monitored data in LabVIEW is transferred to MySQL database server through internet. PHP API executes on the internet server and connects to the MySQL database, which returns the data in plain HTML page in json (Java Script Object Notation) notation, according to the query defined in it. An android application is developed in the Eclipse IDE using java. Internet connection permissions are given in it to connect with Wi-Fi. Data from the database (located in MySQL) can be obtained on the mobile phone by clicking the developed android application on the mobile phone. When the android program is clicked, it connects to URL of PHP API. As a result PHP API connects with the database and returns the data to the mobile phone. Fig 6 shows the screen shot of the developed android application. The developed android application is tested on a smart phone based on android 4.3.

III. Proposed IoT-SN Deployment

To test the functionality of the proposed IoT enabled monitoring system, the proposed IoT-SN was deployed at several places at the institute (DA-IICT) and around the city of Gandhinagar under varying conditions.

Fig 7 shows the deployment of the proposed system at DA-IICT campus during the month of April, 2015. The transmitter node is placed near an office building (where monitoring was easier) and receiver node was kept at a distance of approximately 10 metres from the transmitter node. Temperature, humidity and CO_2 concentration is monitored for the period of five hours. Related results are shown in Fig 8. As can be seen, temperature is seen to be varying between 34.5 °C to 42.2°C, humidity variation is between 21.1 % to 30.2 % and CO_2 concentration is varying between 1182 ppm to 1355 ppm.

After a few iterations, the proposed IoT WSN was tested for the environmental conditions in the city of Gandhinagar, Ahmedabad, India during the same month. The proposed IoT-SN was kept in the open (on top of a car) and readings were obtained for different areas at a distance of approximately 1 to

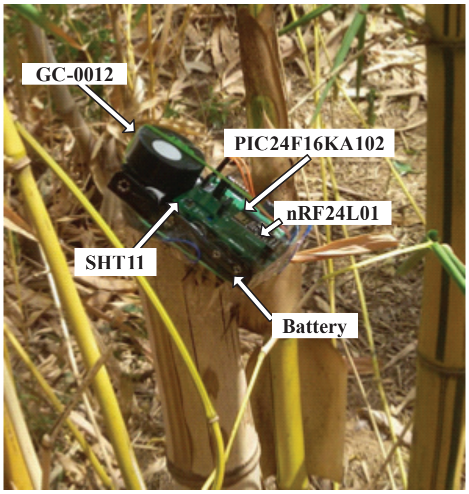

Fig. 7. Deployment at DA-IICT

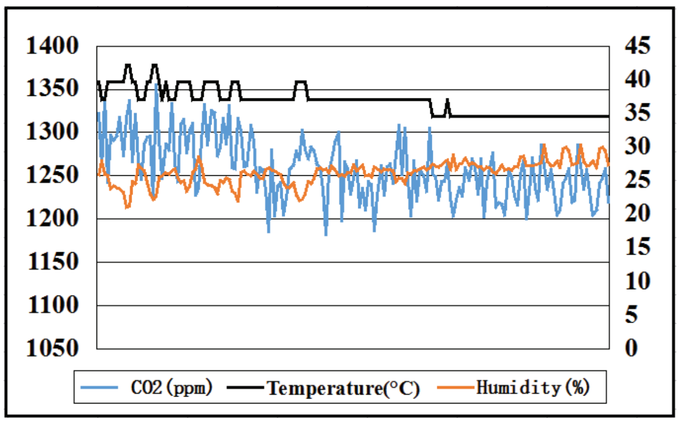

Fig. 8. Results at DA-IICT

2 kms, which are likely to have variations in the CO_2 content. Data was monitored wirelessly through receiver connected to the PC (while on a moving car) and was recorded in an excel sheet through GUI made in LabVIEW for one and half hour. Results shown in Fig 9, represents variation of CO_2, in the range of 1256 ppm to 1439 ppm, for different areas of the Gandhinagar (including the areas nearer to the smart buildings in GIFT city). These results were also available in the mobile device instantly; validating the proposed IoT enabled environmental monitoring system.

IV. Conclusion and Future Work

The proposed IoT enabled environmental monitoring system for monitoring temperature, relative humidity and CO2 has been successfully implemented and validated at various places in the city of Gandhinagar, Gujarat, India. The proposed IoT enabled environmental monitoring system compares well with the similar designs discussed in [1-3]. Apart from sensing temperature, humidity and CO2; the sensor node has a lower power consumption of $4.99mW$. The reliability (valid data at the receiver's side) of the system is approximately 65%

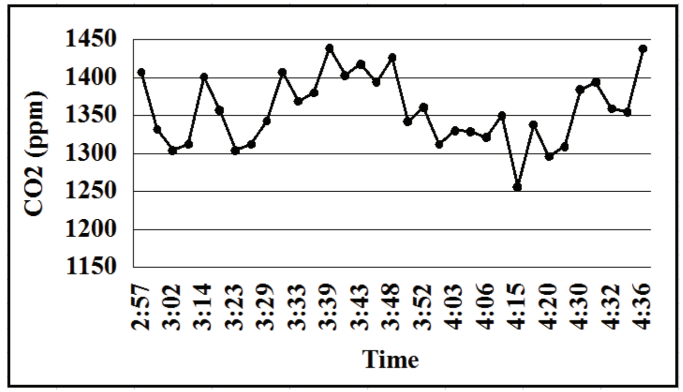

Fig. 9. CO_2 Results for Gandhinagar,Ahmedabad,India

on a multi hopping mechanism whereas the single hopping ensures more than 99% reliability that could be improved and is left as a future work. Furthermore, the predicted network lifetime can be increased simply by expanding the sleep time of the microcontroller which reduces the power consumption significantly. Power consumption of the sensor node is calculated from the different states of the node and is measured at $4.99mW$ that could be further optimized and is also left as a future work. The quantification of the time along with the current consumption of the proposed IoT-SN provides an intuitive way to deploy the sensor nodes based on the available power. Furthermore, the proposed IoT-SN has an added advantage of remote access to the sensing data through an application that is tested on a smart phone based on Android 4.3.

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