Design of a smart indoor air quality monitoring wireless sensor network for assisted living

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D.M.G. Preethichandra
Central Queensland University

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D.M.G.Preethichandra
Central Queensland University
School of Engineering and Built Environment
Rockhampton, Australia
e-mail preethi@ieee.org

Abstract— **Wireless indoor air quality monitoring is the main objective of this research in order to provide real time information for assisted living. The indoor air quality measured in the built environment provides a continuous stream of information for seamless controlling of building automation systems, and provides a platform for informed decision making. Further, this low power sensor network design provides vital air quality information under emergency and hazardous conditions even without grid power for a reasonable time. The proposed system has carbon dioxide, carbon monoxide, propane and methane sensors. This prototype network was first built using a hardware platform available in the market with industrial grade gas sensors. The concept was verified with actual parameter measurements under different real life situations. The results reveal that the domestic indoor air quality may be extremely different compared to what is expected for a quality living environment.**

Keywords— Air quality, sensor networks, wireless sensor networks, gas sensor, online monitoring

I. INTRODUCTION

Indoor air quality monitoring is an essential part of built environment control systems to ensure the indoor environment is in an acceptable condition for living. The process of indoor air quality monitoring involves different technologies namely actual gas sensing, sensor networking, data mining and decision making. There are some prior work on this topic from different points of approach[1]-[3], but this paper proposes an indoor air quality monitoring network for assisted living. Accurate measurement of gas concentrations is the key of air quality monitoring. However, this has to be within the budget of the monitoring system as well. Therefore it is common to select only a number of target gases and sacrifice a little from the accuracy to bring down the cost while getting data within an acceptable resolution.

Online air quality monitoring can be used in many different applications ranging from quality of life improvement to military operations. Occupancy monitoring is a typical application where the number of occupants is estimated from the amount of carbon dioxide detected in a given environment. This information may be used to effectively control the heating, ventilation and air conditioning(HVAC) system in the building or may be used to remotely spy on the population in the room[2,4]. However the military usage is out of scope of this research and this paper mainly focuses on use of online gas concentration monitoring only for civil purposes. This paper mainly focuses on monitoring air quality to improve the living condition in built environments and gather information in disaster management situations.

Carbon dioxide, carbon monoxide, methane and propane are the most common gases of interest in built environments. Carbon dioxide is added to the environment in moderate quantities from respiration under normal situations and in excessive quantities from fires under hazardous conditions. Carbon monoxide is mainly added to the built environment from automobiles. A common source of methane is the common garbage collected at designated areas adjacent to buildings. Propane is mainly from cooking and heating gas lines. Any of these gases may be life threatening if gone above the accepted range for a considerable period of time. Therefore continuous monitoring of each of them is vital in indoor air quality monitoring system.

The HVAC system in a building can be programmed to respond to the indoor air condition monitored from the proposed network. Further, this kind of a distributed wireless sensor network will help the staff of aged and disabled care centers to make decisions on when to move them around for people living indoor for extended periods due to physical disabilities. This involves with different methodologies for data analysis and fit for most suitable model in accordance with the requirement of facility concerned[5,6].

Not only the data from within the building, this kind of network can be easily used to monitor environmenental gas concentrations as well[7,9]. Industrial air quality measurement is another aspect of these networks[10].

II. THICK FILMMETAL OXIDE GAS SENSORS

Semiconductor gas sensors are very common in industrial gas monitoring systems where the gas concentration is represented by an electrical parameter. A common type of gas sensors is thick film semiconductor gas sensor where the semiconductor substrate resistance is varied dependent on the amount of target gas presence. In this research a series of semiconductor thick film type gas sensors with good selectivity has been used for the target gasses. The manufacturer, Figaro(Japan) prescribes precise control signals to the sensor in order to obtain accurate measurements. The sensor consists of two major parts, namely the heater and the sensor substrate. The substrate has two terminals and its resistance is measured as a representation of the amount of gas in the environment while the heater provides the stabilized temperature needed for the measurement. Fig. 1 shows the recommended setting for the measurement where the heater control signal and sensor measurement signal are coming from the sensor node microcontroller while the sensor resistance is read by the same microcontroller.

The manufacturer's specification provides the heater turn on timing and sensor resistance read timing. For example, the carbon monoxide sensor (TGS2442) has a 14ms heating pulse in every second and a 5ms read-control signal immediately after the heater pulse is off. The actual read should occur at the middle of the read-control pulse, in other words 2.5ms after the read-control pulse is on.

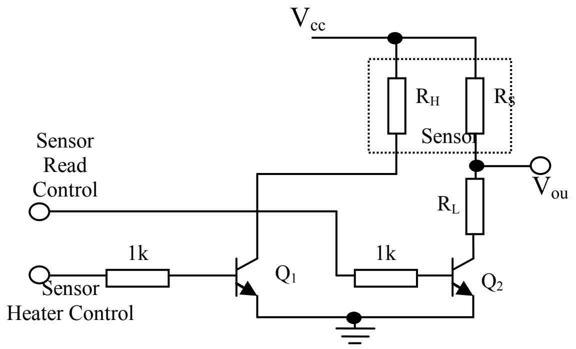

Fig. 1. Schematic diagram of thick film gas sensors and control circuit.

If the current through R_S is i_S, heater resistance is R_H, and Sensor Resistance is R_S, when the Q_2 is turned on by read control pulse,

$$V_{out} = i_S R_L + V_{CE(Q_2)} \qquad --- (1)$$

$$R_S = \frac{(V_{CC} - V_{out})}{i_S} \qquad --- (2)$$

$$R_S = \frac{(V_{CC} - V_{out})R_L}{\left(V_{out} - V_{CE(Q_2)}\right)} \qquad --- (3)$$

The value of sensor resistance can be calculated from the equation 3 using V_{out} value read from the sensor circuit. The microcontroller looking after this sensor sends the heater and read control signals at required intervals and the analog to digital converter(ADC) of the microcontroller converts the V_{out} voltage at the appropriate time. Then the R_S/R_0 is used in conjunction with manufacturer's datasheet to obtain the target gas concentration where R_0 is the resistance of the sensor substrate at a known gas concentration. Sensor resistance R_S is dependant on the ambient temperature and humidity. To have an accurate measurement of gas concentration, the two parameters have also to be measured. The chosen Libelium Waspmote hardware platform has a built in temperature monitor and the humidity sensor has to be integrated on to the sensor module. Further, the sensor control module has a software programmable real time clock which will be useful if a particular node of the sensor is to be programmed to activate at desired time intervals of the day. Moreover, when the network become highly populated with large number of nodes and the links become busier, then the time stamp from each node will be very useful. Since this real time clock is software programmable, the base station can synchronize all the nodes to its clock easily.

III. SENSOR NODE DESIGN

A. *Sensor node hardware*

The intended sensor node design consists of several modules controlled by a microcontroller. The main modules are RF module, control module, sensor module and power module. The RF communication was handled through ZigBee protocol using a XBEE module from Digi International. RF communications module with 2dB antenna which can communicate over 200m line of site distance, which is more than enough for indoor operations.

One of the main objectives of this research is to develop a microcontroller based ultra low power sensor node to gather information on indoor air quality. However, in the first phase, it was decided to use sensor nodes available in the market as proof of concept. The sensor control module prototype has been designed with a Waspmote hardware module available from Libelium Communications. He network operation is explained in the next section.

The selected sensor node has a built in power control circuit which recharges a battery either from USB or from a solar panel of 12V. The control system also provides provisions for eight analog ports which can be configured as inputs or eight digital I/O pins. These were used to implement the control and data busses to communicate with the sensor module. The sensor module consists of carbon dioxide, carbon monoxide, methane and propane gas sensors integrated into it.

B. *Power Consumption*

Power consumption is not a major issue as long as the built environment is connected to the power grid where these sensors can directly be fed from it. However, indoor gas condition monitoring is vital in emergency evacuation situations where the mains power may be turned off under high danger situations or by the emergency itself. Each sensor node has its own rechargeable battery which getting charged from the mains power when available, and automatically switches to battery power whenever the mains power is cut off. The chosen Wasp mote sensor hardware can seamlessly transfer from mains to battery, therefore no rebooting will occur during the changeover. An ultra low-power sensor network node is vital in such situations where it can sense and send information on indoor air quality for a longer time without mains power for disaster management team to make correct decisions.

However, the manufacturer recommends that the gas sensor in the sensors module needs to be heated-up for more than two hours before taking reliable readings. Therefore this module has to be powered up continuously, but the average power consumption by the sensor is very small as the heater pulse is a 50mA, 14ms pulse in every 1000ms. There are different options available for heater stabilizing where Jelicic et.al. [11] propose a similar results for a short term turned off sensor compared to a continuous turned on sensor.

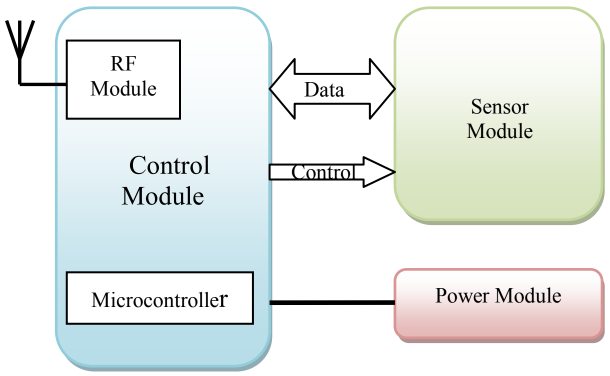

Fig. 2. Sensor node schematic diagram

Fig. 2 illustrates the block diagram of the proposed sensor node. A separate node without the sensor module act as the base station or the gateway to the host computer. Each RF module has a 16digit IP address and they can be configured to have a common network ID or different network IDs. Depending on the requirement these nodes can be reprogrammed to change the network topology. Only the last six digits change from RF module to RF module and any particular sensor node using a RF module with known IP address can directly be addressed without disturbing the other nodes in the neighborhood.

Under the current configuration all network nodes in the network have the same network ID making the RF communications local to the network. The base station is connected to a PC via USB port and the measurement data are fed into a database in the PC. However the base station can send data via RF link to another node connected to a remote PC in a different geographical locations for emergency conditions.

The network topology selected for the initial testing network is the star topology with auxiliary multiple hop links to find a lost node in case of repetitive direct communications problems. This situation is a common scenario in built environment as objects may come in between two RF modules blocking their line of sight. If the obstructing object acts as a RF signal absorber then the direct link will be lost. Therefore the network is programmed in a way that the established network links are tested for a predefined number of times for transmission and if not successful the base station will send a command to adjacent nodes to relay the message to the missing node.

C. *Data Fusion*

The data obtained from each node has to be analyzed individually to check whether it has gone beyond the maximum allowable level for that particular gas for that particular node location. Then the data obtained from each node for multiple gasses need to be fused to make a decision to decide whether it is a good living environment or not under the current concentrations of them. Next level is to fuse data obtained from multiple nodes to make a decision on the suitability of the complete sensor network area for human health.

IV. Implementation

The first stage of proposed sensor network was implemented using *Libelium Waspmote* sensor nodes and gas sensors from *Figaro*. Each sensor node is programmed to measure the target gas concentration in real time and transmit measured value upon receiving a request from the base station. Under this scheme the sensor node is actively listening to the network base station and as soon as an interrogation signal is received, it will check the MAC address of the packet to decide whether it is for it or not. Since the Base station signals are on broadcast mode, every node in the network will receive all the requests, but respond only if it was addressed to them.

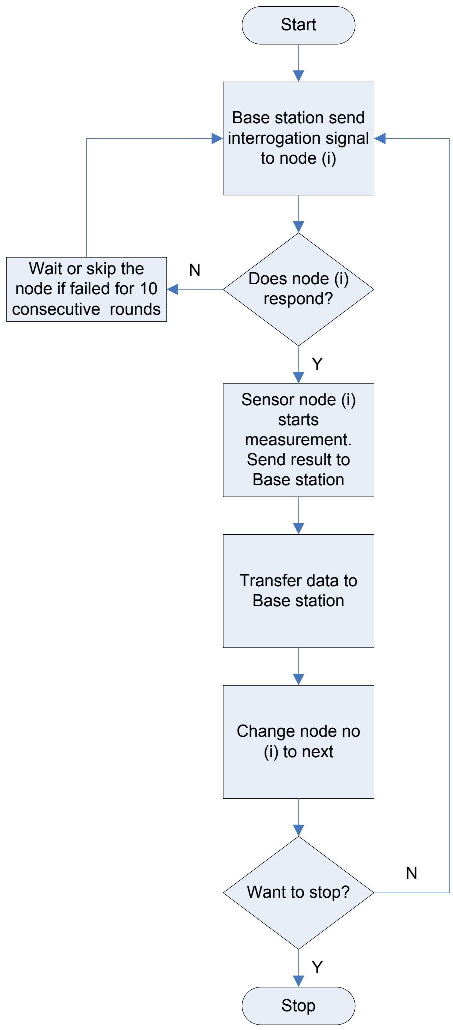

Fig. 3 Flowchart of sensor network version 1 implemented

Fig. 3. Shows the flow diagram of the sensor network version 1 operation. The main disadvantage of this version is that each sensor node is awaked full time and consumes full amount of power. However, this version is better suits for gas concentrations monitored at very short time intervals because

there is no time to put the nodes into sleeping mode to save power.

As mentioned earlier, the base station will activate direct links to individual sensor node in a round robin operation, however it may use multicast transmission commands to recover a missing node in the network. If a particular sensor node has difficulties for direct RF communications with the base station for a prolonged time, the base station will send an alarm to system administrator to look in to the matter.

In the version 2 of network design, individual nodes will autonomously measure the gas concentrations at set time intervals and store them against real time in a local database. They will be transferred to the base station when interrogated by the base station and the successfully transmitted data will be deleted from the local database. Fig.4. shows the operational flow chart for this.

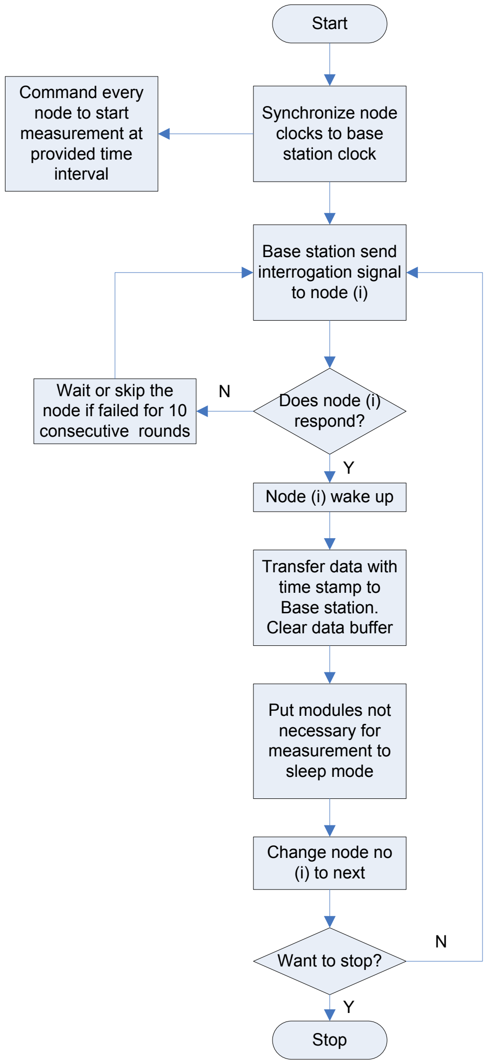

Fig. 4. Flowchart of sensor network version 2 implemented

This version of the sensor network is of particular interest for disaster management situations when the mains power is cutoff. The sensor nodes can provide gas concentrations for a longer period with the saved battery power with partial sleeping. However, the sensor module has to be powered on for at least a couple of minutes before making any measurement.

In the first stage of the project a carbon dioxide sensor module was used with a sensor node to measure indoor CO_2 concentrations in a bedroom during the night time. The sensor node measures CO_2 concentration at every 20 seconds and sends measurement data to the base station upon an interrogation over the RF link using ZigBee protocol. The selected bedroom is 4m x 4m in size and all windows were closed for two hours without any occupants before starting the measurements. The sensor node was placed 1.5m above the ground closed to the wall opposite to the bed head. Room fan or air conditioner was not operated during the night.

V. Results and Discussion

Figure 5 shows the measured CO_2 concentration in the selected bedroom during the night from 7:00pm to 6:00am. The graph clearly shows that the CO_2 concentration is in the range of 400ppm, which is the standard concentration in clean air, before the occupants were accommodated. It starts to rise at a lower rate when the occupants were in but still the door was open while the windows were closed. The next section of the graph shows a linear increment in CO_2 concentration when all the openings to the room were closed while the occupants were sleeping. Last section is opened doors and windows with no occupants inside the room in the morning. It can be clearly seen that the fresh air from outside has brought down the CO_2 concentration rapidly when the windows and door were open. The couple of sharp spikes shown on the graph are due to the operator go close to the sensor node to check the operating conditions and breathing out at very close proximity to the sensor.

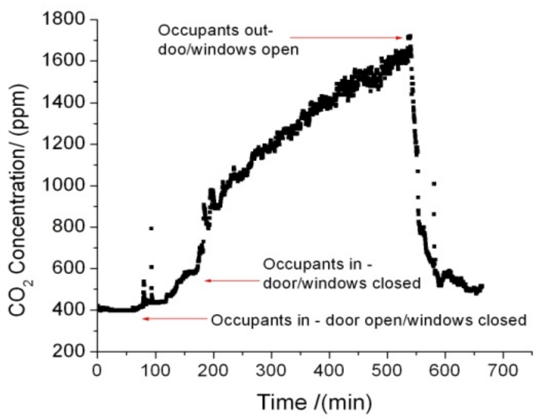

Figure 5. CO_2 concentration measured in a bedroom overnight

Even though the occupants didn't notice it and got used to this condition for a long time, the carbon dioxide concentration is more than four tines the normal and well above the permissible level for healthy living. This measurement data can be used to activate ventilation system in an automated HVAC system to provide fresh air. Therefore this kind of continuous air condition monitoring will be an essential integrated part in future built environment systems to ensure a good quality of living. This can be achieved by incorporating this data with suitable algorithms to control the HVAC system.

Carbon monoxide, methane and propane sensors work similarly in the network and development of dedicated and optimized low power sensor nodes is underway.

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