MPI BASED SIMULATOR STUDY FOR INDOOR AIR QUALITY MONITORING

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Abstract

Indoor air quality (IAQ) monitoring is getting more attention from people because of health, comfort, and energy efficiency considerations. Indoor air pollution sources are gases which are emitted from synthetic materials in the buildings and human breath. These gases can be detected by devices equipped with electronic sensor arrays which are installed rooms in a building, and they convert gas concentrations to digital data. This data must be processed to create information for monitoring system and to control ventilation system each individual room. Collection of digital data from multiple rooms of a building can be achieved by different technologies. In this study, MPI (Message Passing Interface) is preferred due to its simplicity and scalability. Gas concentration measurement devices are simulated by software on virtual hosts. MPI routine libraries are installed to the simulated sensor nodes, i.e. virtual hosts. A graphical user interface (control panel) is implemented to form building components such as rooms and sensor nodes. The sensor data transfer to the central server is achieved by MPI. In the central server some graphical tools are implemented to show air quality status of the rooms by coloring rectangular shapes accordingly.

Key words: Indoor Air Quality (IAQ), Distributed monitoring systems, Message Passing Interface (MPI).

1. Introduction

In recently, people spend most of their time in the indoor environments. The amount of indoor pollutants is higher than outdoor. So, low indoor air quality becomes a problem. VOCs and CO which are pollutants of indoor environment affect chronic health problems, cancers and people's psychology. CO_2 gas causes low productivity and performance. Therefore, indoor air quality monitoring systems for providing the continuity of the habitable conditions in building are important.

Indoor air quality monitoring process consists of different technologies such as gas sensing, sensor networks, data processing and decision mechanisms. There are many important studies that were use different perspective about IAQ monitoring subject [1,2,3,4]. However, all they used fabricated environments because of limited research budgets. Some of these studies, just a

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few target gases were chosen and monitored. Hence more detailed research is needed in the area.

In the literature [5,6,7], different distributed sensor systems were achieved for monitoring indoor parameters such as temperature, humidity, odor and pollutant gases (e.g. CO) using air quality sensor networks. Pollution that was emitted by people was measured using fixed and mobile sensors in an environment. Fixed sensors are expensive and offer realistic results. But, it is very difficult to place to every location where people are in. Mobile sensors are cheaper and measuring is easier than fixed sensors. However, the measurement results are not reliable. In study of [8], a hybrid system was proposed with using fixed and mobile sensors and more accurate results were said to be obtained.

There are some similarities between IAQ monitoring systems and distributed data processing systems [9,10]. In IAQ systems, sensors are placed distributed locations independently, the sensor data are collected at the central server. Besides, transferring and processing of the data, activation of the control systems are done in the distributed parallel systems too. In the study of [11], intelligence and distributed monitoring system was designed for IAQ monitoring in the health care. Proposed architecture was very flexible because of its distributed nature. In [12,13,14,15], it is mentioned about the multi agents that were used for collecting and organizing sensors data, testing their accuracy in the distributed systems are very useful. In the literature [16], producing data in specific intervals, packing, data transmission and processing stages were described with using distributed system.

During the design of indoor air quality monitoring systems, many questions arise. Which types of sensors are used, where these sensors are placed to, how do sensors and control unit communicate, how is the data analyzed etc.? Answers of these questions affect the performance, accuracy and cost of the systems. For example, while high selectivity sensors are expensive, the cheaper sensors results may not be always true. But, if considering the size of whole systems, the cost of the system that consists of expensive sensors must be thought. After deciding the sensors, their locations must be determined. If true locations are chosen, all measurements can be done with optimal sensor counts, and then; measurements results must be analyzed for meaningful data. A connection must be provided between the distributed sensors and the main server for data transmission. However, the design parameters must be determined and optimized in advance not to cause a bottleneck during the transmission. All of these design problems make these systems very complex according to individual systems. Solving these problems using trial and error methods will cause waste of time, work force and material losses.

The purpose of this study is to develop a simulator that offers optimal solutions to the problems for online IAQ monitoring. This work makes the following contribution:
1) In the IAQ monitoring studies, concentration of CO_2 gas is investigated generally. Therefore, virtual sensors have been coded by characterizing of the CO_2 (TGS4161) gas sensor. They are added to the simulator software as a library.
2) Any building plans can be modeled by users graphically. This makes the simulator user friendly.
3) Measurement results have been processed and converted to meaningful data. These data are sent to the graphical user interface.

4) MPI routines are used instead of the complex communication protocols for data transmission.
5) The system can be configured on the fly by provided menus, and the graphical results can be seen from the tools as user interface.

2. Materials and Method

In this part, message passing interface (MPI) used for data transmission is explained, and general architecture of the simulator system is presented. In addition, modeling information about CO_2 gas sensor is presented.

2.1. Message Passing Interface (MPI)

MPI (Massage Passing Interface) is a library that is used for parallel programming and creating distributed systems [17]. Many applications that require high computing performance and network communication need to use MPI. It works according to MIMD (multiple instruction multiple data) principle. Communication with each of processors that execute simultaneously is done by message passing methods over the network. Each MPI processes have local program states that cannot be intervened by other processes.

In this study, sensor cells and main server have been thought as different nodes or processes. General architecture of the simulator system has been shown in Figure 1. Sensor cells have been designed as slave machines whose number can be increased or reduced according to the user's request. Main server has been designed as master where data has been collected in. Bidirectional communication has been performed using MPI routines between master and slaves.

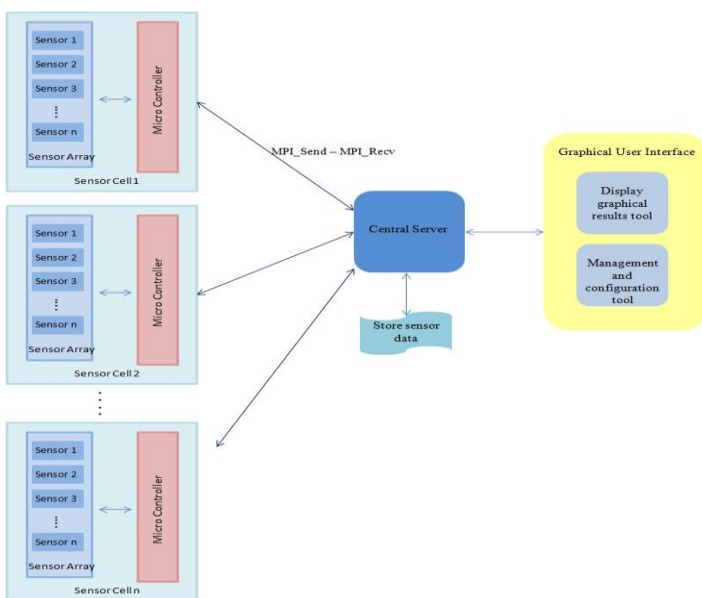


Figure 1. The architecture of the simulator system

2.2. Indoor Air Quality Gas Sensors

In this study, TGS4161 CO_2 gas sensor of Figaro that has been used for indoor air quality studies frequently. Its response simulation has been coded. So, resulting graphics can be examined to infer gas density change. We collect required response details about the sensor from the catalogs [18]. A model is set based on the response graph of the sensor. So, responses to other gases are neglected, assuming it only reacts to CO_2 gas. The TGS 4161 has a range of carbon dioxide detection of 350~10,000 ppm. The CO_2 sensitive element consists of a solid electrolyte formed between two electrodes. By monitoring the change in electromotive force (EMF) generated between the two electrodes, it measures CO_2 gas concentration. The threshold of CO_2 concentration is 1000 ppm for real good IAQ. So, target gas concentration must not exceed the threshold value [8].

3. Simulator Design and Implementation

3.1 Sensor Cells

Components of a sensor cell are sensor array which consists of n sensors, microcontroller, A/D converter, a power source and external memory as seen in figure 2.

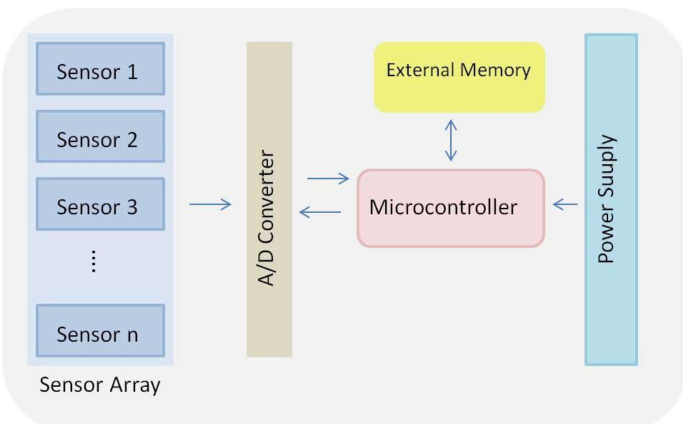


Figure 2. A sensor cell and its components

The activities in the virtual sensor cell are put into a flowchart shown in Figure 3. When the simulator runs first, sensor cell configuration is done by main server. So, the sensor numbers and time interval for sending data are determined by the user. After the start signal generated by simulator user, the sensor responses are produced according to scenario files. The data is stored in local memory of the sensor cell and is packed for every 10 minutes (The time interval is set as 10 minutes). The time stamp is added to the packet and is sent to the main server. There are sensor cell id, produced sensor response data, temperature and humidity information in each packet. After the packet sent, these sensor responses are removed from the local memory.

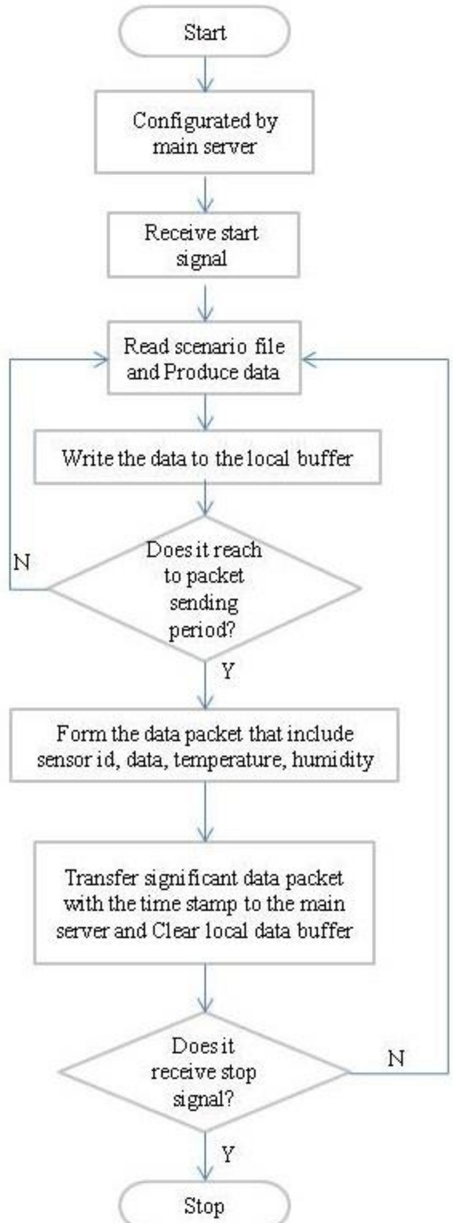


Figure 3. Flowchart of a virtual sensor cell

3.2 Main Server

The flowchart of virtual main server is presented in Figure 4. The main server configures the sensor cells firstly. Then, it receives packets from sensor cells periodically and stores them in a database. These packets are analyzed and converted to graphical forms for user interface. MPI (message passing interface) is used for communicating between main server and every sensor cells.

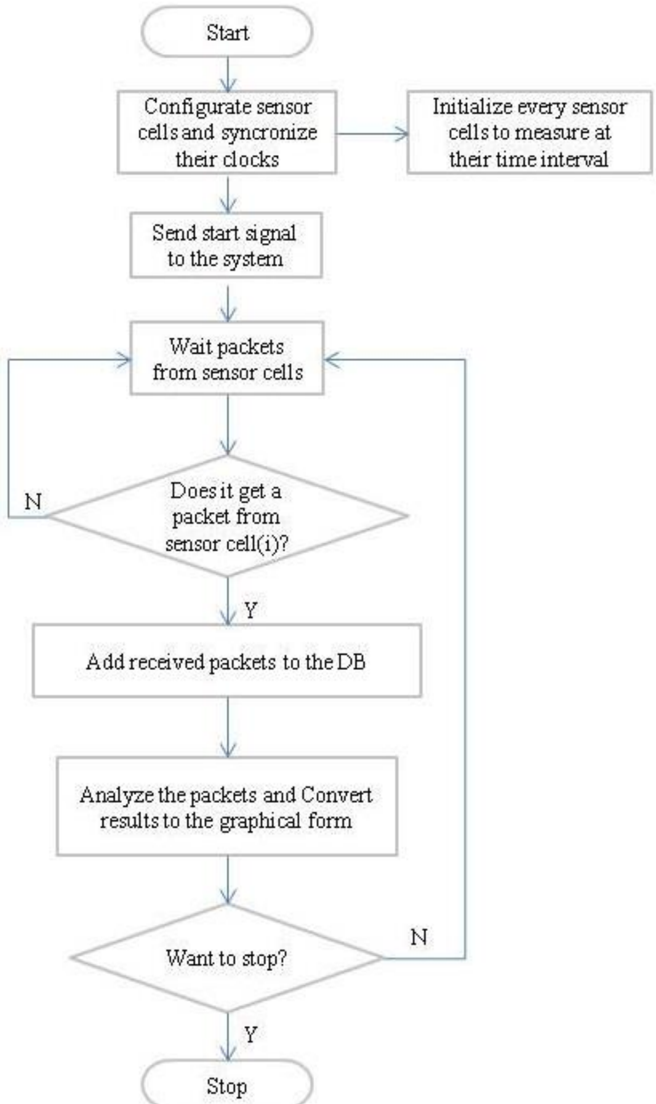


Figure 4. Flowchart of virtual main server

3.3. Implementation

In Figure 5, the GUI of Admin is presented which is designed to perform management tasks, and includes different sections:

- Editing sensor cell allows to decide sensor cell's geometric type and to add defined sensor type (CO_2, CO etc.) in it. A user can form sensor cells whatever needs and add to the database for using later again.
- Editing scenario permits to prepare scenario files for sensor cells. A user can select gas type, interval of the blown gas and the amount in terms of ppm. Temperature and humidity

values can be added. Scenario files are prepared by user according to periods of the human density in the simulated building. When human density is high, CO_2 emission will be excess in the environment. User can identify these periods and amount of the CO_2 approximately.

- Building properties section provides textbox to enter room count, and then, room dimensions can be entered. So, user can get visual sketch.
- Acquisition data allows calibrating time interval while sending data packets. In this study, the time interval is determined as 10 minutes. Sensor cells send their data packet to the main server every 10 minutes.
- Alert section permits to fill threshold of gas concentration that is CO_2 in this paper, minimum and maximum values of temperature and humidity. Finally all of configuration is send to every sensor cells (sensor nodes) using send configuration button, and then simulation can be started.

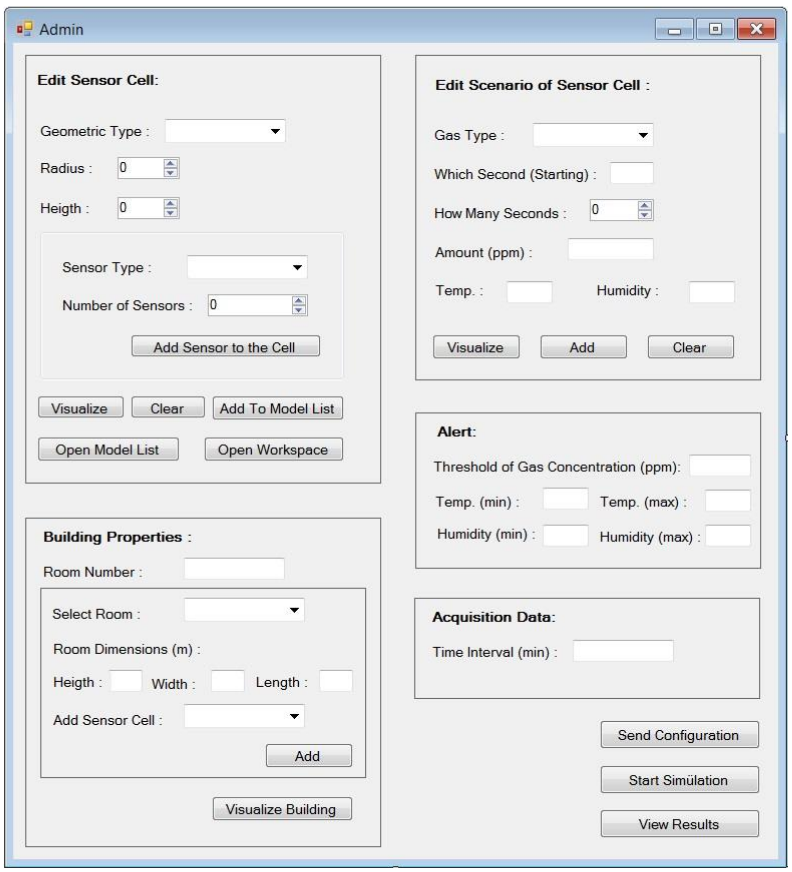
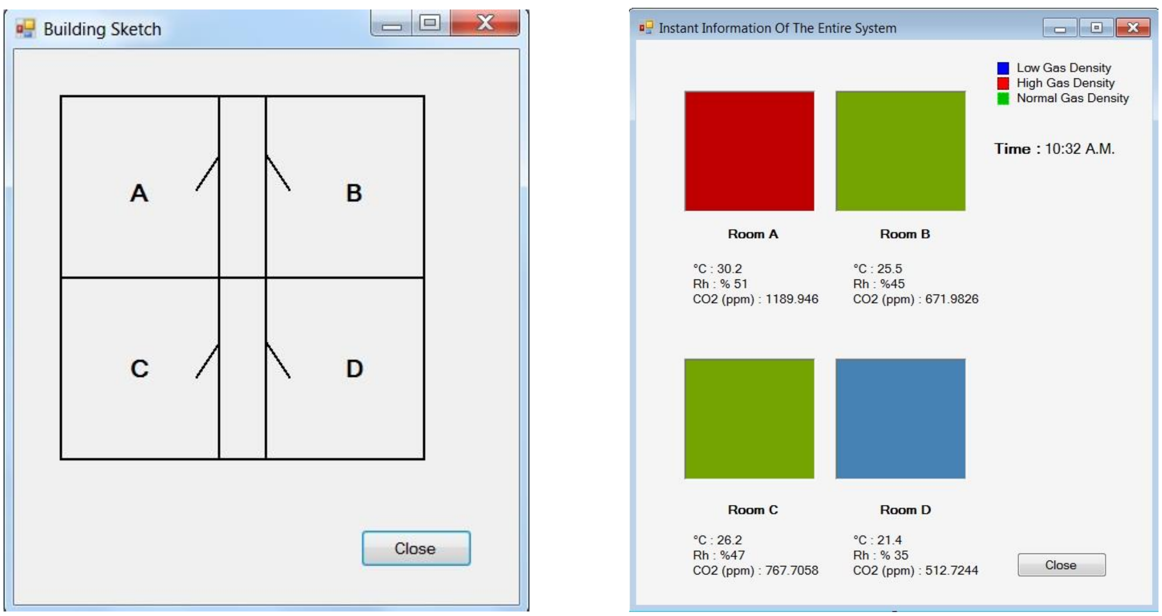


Figure 5. Admin GUI for configuration to the system

4. Results and Discussion

In this study, a simulator has been developed for online indoor air quality monitoring systems and only CO_2 gas has been modelled since CO_2 is the most important gas for the indoor air quality studies. TGS4161 sensor that is known as tin oxide sensor has been modelled and added as a library into the simulator. For future works, it is aimed that sensors which have changeable frequency ability like QCM, SAW and which measure the pollutants such as CO, NO2, VOC and etc. will be modelled.

When the simulator is started, each sensor cells that have been edited for the rooms produce results according to their scenario files and the building has been formed as defined dimensions. When the view result button is pressed, the user can monitor building's architectural sketch basically and air quality status of the rooms by coloring rectangular shapes accordingly. These result forms have been seen in Figure 6.a. and 6.b.



6.a. **6.b.**

Figure 6 6.a. Building sketch 6.b. Instant information of the entire system

In Figure 6.b., air quality status of every room could have been monitored in the building. Temperature, humidity and CO_2 concentration values of the rooms have been presented. Considering all conditions, the air quality has been shown with using color graphics. Red represents bad air quality, blue symbolizes good air quality and green informs about the threshold value of air quality.

In this study, a number of CO_2 sensors are added into the sensor cells that were formed a variety of geometric shapes. And then, virtual test environments have been created by writing scenarios that were very close to the actual ambient conditions. But in the next studies, the environment will be modeled close to reality and then dynamic input will be acquired besides synthetic data.

Collected sensor responses have been packed and transferred to the central server. So, there has been data transmission from sensor cells to central server continuously and MPI has been used for it. But, if we consider increasing the number of sensor and sensor cells, some topics such as topological properties of the system, traffic congestion over the server must be examined. In this way, optimal designing parameters of the distributed gas measurement systems will be determined by the future versions of the simulator.

Through this simulator, optimal system designing can be done before it has been performed. Number of sensor cells and sensors in the rooms can be determined. If we consider increasing the number of sensor and sensor cells, traffic congestion over the server and determining place of the data processing (in nodes or central server) can be examined. And also, all of them can be done without any cost above all other studies.

Conclusions

There are many academic researches about indoor air quality monitoring in the literatures. In most of these studies, real time monitoring systems have been used for IAQ. Testing such gas measurement or monitoring systems is time consuming and costly process.

Unlike other studies, in this study, a simulator has been developed for online indoor air quality monitoring systems. In the simulator, a CO_2 gas sensor, sensor cells, their schedule plans and main server have been modeled virtually. And also, any buildings can be modeled in our system. Communications between sensor cells and the central server are realized by MPI routines. In this way, both data processing and data packets transfer operations have improved significantly.

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