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Low Cost Air Pollution Monitoring with Wireless Sensor Networks

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***Abstract*—The reasons to use wireless sensor network (WSN) technology are convenience to nature, reliability, flexibility, low cost, self-organization, energy balance inside the network and easy establishment. In this study, an air contamination measurement and visualization system by the use of WSN is developed. Sensors which are capable of quantifying the density of Methane, carbon monoxide, isobutane, ethanol and hydrogen gases are programmed, and the density of carbon monoxide gas in each related region has been measured and processed to determine air pollution. Data measured by sensors is transferred to the visualization interface to transform the data into meaningful information. Changes in air pollution are shown instantly on a map given in the web interface. Lastly, the obtained results are compared by the results provided by Ministry of Environment and City Planning and the accuracy and the efficiency of the system is discussed.**

Keywords— Air pollution monitoring; air quality; wireless sensor networks; MATLAB; ZigBee.

I. INTRODUCTION

The importance of Wireless Sensor Networks (WSN) is ever increasing with the developments in the new technologies. Using wires in systems consists of many disadvantages like the size of physical dimensions of hardware structures and inadequacy of using it in some environments. To eliminate the disadvantages it is necessary to use WSN and in fact sometimes it is an obligation. The expectations from WSN technology are increasing with the technological improvements. For sure, removing wire usage is not the only expectation about WSN. Besides, ease of use in nature, reliability, cost efficiency, maintainability, and ease of establishment are the expected benefits of WSN technology.

WSN came up in the beginning of 1980s. It became an important research subject with the improvements in micro electro-mechanical systems (MEMS) and wireless communication systems in 1990s [1]. According to the studies in the literature, it is concluded that WSN simplify the life significantly and enhance the efficiency of the applications because of the features such as accuracy, reliability, flexibility, cost efficiency, and ease of establishment. As a result of the researches, it is thought that WSN can be used in air pollution measurement to improve the efficiency in this topic. There are many methods to measure air pollution in the previous studies, but most of them are realized by stable stations and there must be many stable stations to monitor a large area. For each station a hardware-based system is established and the cost of such a system is proportional with size of the examined area because each station has a specific coverage area. Instead of many stable stations, less number of mobile stations can do the same.

There exist 125 air quality monitoring stations in Turkey and only 3 of them are mobile stations [2]. These stations are quite sensitive and adjusted properly, but they are expensive [3]. On the other hand, WSN are much more suitable because of low-cost establishment, easy and fast configuration in air pollution monitoring systems, and ease of distribution and usage in real environment unlike traditional air pollution monitoring systems [4], [5].

In this study, sensors which are capable of quantifying the density of Methane (CH_4), carbon monoxide (CO), isobutane (C_4H_{10}), ethanol (CH_3CH_2OH) and hydrogen (H_2) gases are programmed and air pollution is monitored from the density of CO gas. The purpose of the study is to reduce current high cost, which appears in using constant and mobile air measurement devices, thanks to WSN. Thus, there will be a facility to set up air quality monitoring systems in numerous regions since the cost is reduced. Air quality will be checked at any time and it will be possible to take precautions in case of negative situations. It is obvious that larger number of people will benefit.

This paper is organized as follows: area of usage of WSN and literature review is given in Section 2, realized application and system evaluation is given in Section 3, and finally, results and discussion is given in Section 4.

II. RELATED WORK

Literature review is divided into three categories to light the way for the realized system and other studies. These are general area of usage of WSN, traditional air pollution measurement systems, and WSN especially in air pollution measurement.

A. Usage Area of WSN

Wireless sensor networks were applied to many different fields and still go on being applied. WSN technology which was previously used for military

purposes becomes indispensable as a result of the needs of people and lower cost. Wireless sensor networks are appropriate for many applications like miniaturizing and integrating physical sensors, embedded micro controller, and radio interfaces on a single chip. These sensors can also be used for nature monitoring, health applications (patient-doctor follow-up, monitoring patient's physical or psychological situation, etc.), energy supply and transfer systems (in production, distribution and consumption structures), home and office applications (smart kinder garden, home, automobile, etc.), analyzing remote locations (tornado motion, forest fire detection, air pollution analysis, etc.), determining full or empty areas in a car park via sensor networks and so, using it more efficiently, providing security in shopping centers, car parks or similar complexes, using for military purposes like determining enemy motion and protecting country borders, vigilance systems against terrorism attacks, traffic pattern monitoring and navigation, plant monitoring in cultivation, and infrastructure monitoring [6].

One of the most important application fields of WSN is health monitoring [7],[8]. There are mostly useless wires between the monitoring system and sensors in physical treatment systems. Those wires limit the motions and activities of the patients and therefore the measurement may be affected negatively [9]. Alexander et al. provide a study called "Wireless sensor Networks for personal health monitoring: Issues and an implementation". They first give general information about WSN and then, develop a medical application [10]. They developed a WWBAN (Wearable Wireless Body Area Network) prototype and evaluated the correlation between ECG (Electrocardiography) activity and human motion. In [11], there is some information about WSN which are especially used in sensitive cultivation. WSN are used for the purposes like collecting effective data from soil and processing it, maximizing plant yield and effective usage of the sources to minimize harmful effects of chemicals which are used in production. Today, using WSN in sensitive cultivation is an attractive topic. Sensitive cultivation needs proper irrigation, fertilization, and pesticiding at correct time and correct amount [11]. Liu et al. developed an application of WSN to monitor wild life after mentioning its importance in ideal observation [12].

The architecture of WSN is examined in another paper. Researchers elaborated a system to monitor and control some environment parameters like temperature, moisture, light, and pressure and emphasized that WSN are quite useful in environment monitoring. They mentioned reliability, robustness, flexibility, and autonomy advantages of using WSN [13].

B. Conventional Air Pollution Measurement Systems

Air pollution, a result of urbanization and modern life, has a universal effect as well as its local or regional effects. Air quality is cared around the world, because air pollution has significant negative effects on human health. Scientific society and related authority are focused on monitoring and analyzing atmospheric pollutant concentrations to solve the pollution problem and to decide on a strategy. It is very important to develop an appropriate tool for understanding pollutant levels in a region. This tool must provide accurate and understandable information about the level of air pollution while it is useable for taking precautions to protect society health [14].

Lay et al. developed an air quality measurement system based on LED technology to measure the air quality that the patients breathe in operation rooms of hospitals. In this study, they analyzed LED technology and developed the application after explaining air quality measurement in indoor areas [15].

Stable and mobile stations are used in Turkey to monitor air quality. Measurement data which is collected in measurement stations are transferred to data processing center via GPS modems on a special network (VPN) and monitored. Average data which are measured hourly by the stations are analyzed and monthly or annual reports based on those data are prepared and published (T. C. Ministry of Environment and Urbanization, 2015).

C. Air Pollution Measurement with WSN

A system (MAQUMON) which is planned to monitor air quality by mobile vehicles with gas sensors is realized in [16] for a wide area. There are sensors which are capable of measuring the densities of ozone (O3), carbon monoxide (CO) and nitrogen dioxide (NO2) on the nodes and a GPS unit to find the vehicle location. Also, there exists Bluetooth on the vehicle to facilitate network transition. Once the data is gathered, it is transferred to storage unit and stored. Then, it is forwarded to base station via Wi-Fi. MAQUMON measures air quality and pollutant distribution. However, it needs to enter coverage area of the base station to transmit observed data and so, instant transmission of data is impossible. This is an undesirable situation where instant transmission is required. In [4], the researchers developed a prototype to monitor air pollutants by using WSN. They designed a sensor board, APOLLO, to track air quality. Data is first collected from different air components and then transferred to a host. Commercial off-the-shelf gas sensors are used to provide inexpensive application. Different sensors are mounted on the board. WSN technology is combined with data transmission technology. However, the application is not tested in a real outdoor environment and stands as a prototype.

WSN and mobile phone are used together and an air quality monitoring application is developed in another paper [17]. There is a gateway as an administrator of the nine sensors in the application and it transmits the collected data via SMS (Short Message Service) of GSM. This SMS consists of temperature, humidity, some gas levels, some meteorological parameters, and battery level. Data is sent to database, MySQL, via GSM module. Although they did

not make any analysis on energy consumption, it is not difficult to predict that there is a big energy need during the sensors and the mobile phone communicates. [5] carried out carbon monoxide and smoke measurement with WSN. Their system moves the results to the internet. This is not an appropriate mechanism since connection with internet service providers is not always possible for WSN which are mostly set up to more challenging and scattered places than wired networks. In another paper, both mobile phone and internet technology are used together [18] and it is trivial that the proposed system is not energy efficient because of the reasons stated for above references.

III. Air Pollution Measurement System

A. System Implementation

Waspmote sensors [19] and use ZigBee communication protocol and a sink are used as system components. ZigBee is a protocol used in personal area networks and it uses smaller and lower power digital radio when compared with IEEE 802 standard. Some codes, written in NesC programming language, are embedded into the sensors to make them communicate with each other and transfer the data measured by the gas sensors to desired destination (whether to base station or to another sensor).

Next, the prepared sensors are placed into five distinct locations of Duzce University Konuralp Campus. Those locations are

- Rectorship building
- Faculty of Forestry building
- Faculty of Medicine building
- Sport Center
- Dormitory building

Receiver unit is placed into Faculty of Engineering and data acquisition/processing are realized from there. Figure 3 shows the locations of the sensors (in yellow) and receiver unit (in pink) on campus plan.

Name of the sensor, gas density value and time information are taken from each node via gas sensors. CO gas is based for calculating air pollution. Gas density value is calculated by the graph (given in Figure 1) provided by the instruction book of gas sensor. To make the calculation process easier, a fifth degree curve is fitted by MATLAB, equations and the coefficients are obtained. This fifth-degree function is given in (1).

$$Y = p1 * x^5 + p2 * x^4 + p3 * x^3 + p4 * x^2 + p5 * x^1 + p6,$$

$$p1 = 2.0361e-06$$
$$p2 = -0.0001888$$
$$p3 = 0.0061546$$
$$p4 = -0.086393$$
$$p5 = 0.49191$$
$$p6 = 0 \quad (1)$$

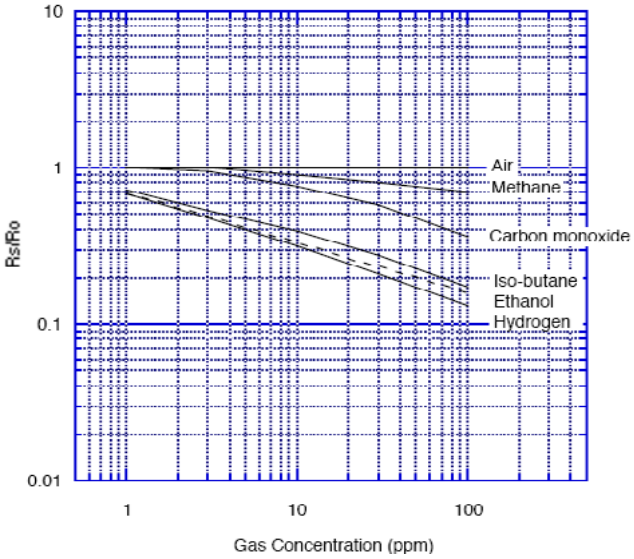

Fig. 1. *Gas sensor graph [12]*

Data measured by the sensors are not only used instantly, they are also stored in a database. First step of storing is to record the data into a text file via HyperTerminal component of Windows Operating System. Data about the name of the sensor, gas density value and time are recorded to that text file at 10-minute intervals as shown in Figure 2.

Second step of storing process is to save the data which is in the text file into the database. MySQL is selected as a database management system since it is open source. A "WSN" named database is created in MySQL and the data is transferred there via an interface prepared by using PHP programming language to store in tables. The value of CO density is calculated by using the value of compound gas density and the function in (1). Then, this value is recorded to the database and degree of air pollution is calculated. The degree of air pollution is gathered by the values provided by the Ministry of Environment and Urbanization of Turkey as given in Table 1.

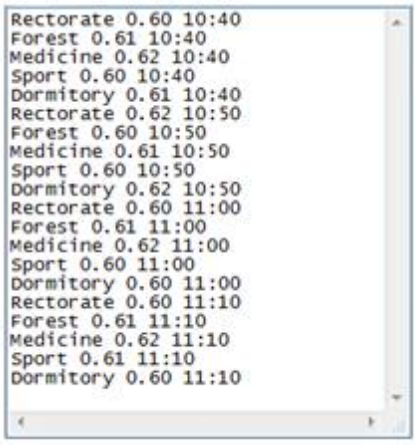

Fig. 2. *Data received from the sensor to be stored in text files*

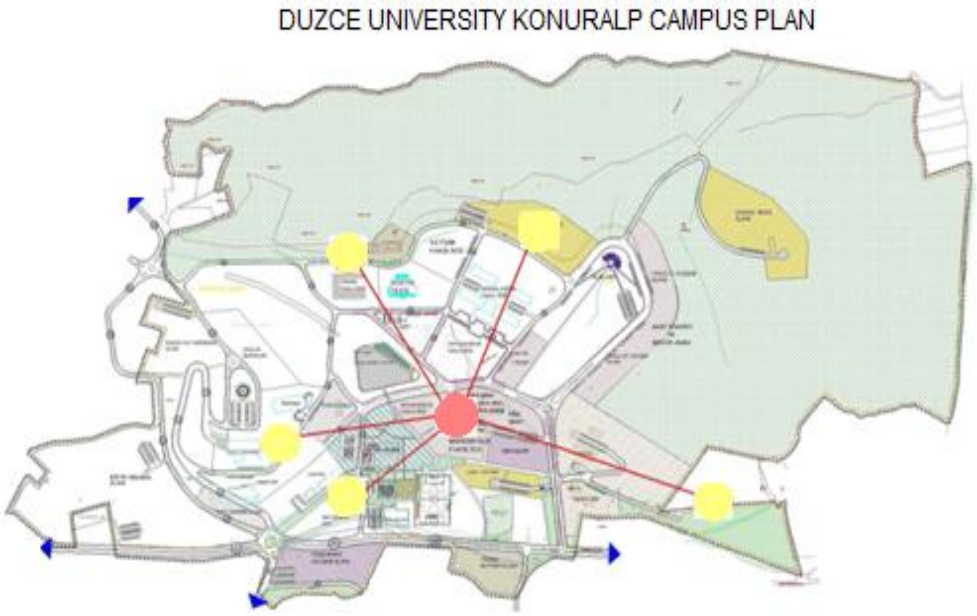

Fig. 3. *Sensors (yellow) and Receiver Unit (pink)*

TABLE I. DENSITY DEGREE OF CARBON MONOXIDE GAS [18]

Density Degree	Carbon Monoxide (µg/m3)
Very Good	0,0 – 1,9
Good	2,0 – 7,9
Enough	8,0 – 10,9
Medium	11,0 – 13,9
Bad	14,0 – 39,9
Too Bad	> 40,0

Furthermore, the CO density in the database and the values in Table 1 are compared and the degree is calculated. PHP is used for this operation. Colors in Figure 4 are determined to show the pollution degree of the regions in Figure and those colors are used in the web interface.

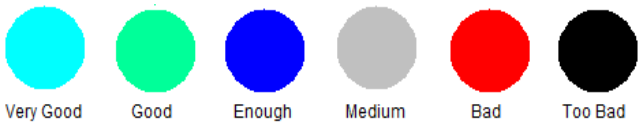

Fig. 4. *Pollution Degree indicates the Color Values*

B. System Output

In this study, carbon monoxide (CO) gas density value is measured after sensors are placed into five locations in Duzce University Konuralp Campus. The values are stored via HyperTerminal and then, transferred to the database in MySQL called WSN. Those transferred data is used to extract the density of CO, and so, the air pollution inside the equation given. It is also transferred to the interface and the results are visualized. Those results are shown on the map with the colors given in Figure 4 and updated in every 10 minutes (see Figure 5).

Carbon monoxide gas density value and the time at which it is measured in a specific location can be accessed by using “Choose Region” option. Once the location (Rectorship, Forestry, Medicine, Sport Center or Dormitory) is selected, the value of CO and its measurement time can be seen. The average value of CO value at different times is given in Figure 6.

C. System Evaluation

Wireless sensor networks which are equipped with different gas sensors are actively used for monitoring air quality. Air pollution monitoring systems are mostly designed in a wireless manner via the rapid developments in communication technology, network technology and remote sensing technology nowadays. Now, air pollution monitoring systems mostly include GSM, GPRS, and etc. modules. But, those modules require both high cost because of frequent data transmission and they bring high complexity in terms of configuration and maintenance. On the other hand, WSN provide advantages with its simplicity and low cost features [4]. Also, since the sensors of the proposed system are capable of detecting multiple gases at one time, there will be a significant power saving when compared with a system with separate sensors for multiple gas detection. Besides, it is concluded that ZigBee technology is more advantages than Wi-Fi and Bluetooth [20].

Air quality values of Konuralp district of Duzce city which are provided by the Ministry of Environment and Urbanization are given in Figure 7. It might be seen that the formal values and the values obtained by ZigBee based WSN system (see Figure 6) are very close to each other. This result implies that sensors are reliable and the system works properly, i.e. data transmission/retrieval works well. Monitoring air quality is realized by a mobile application with lower cost thanks to WSN.

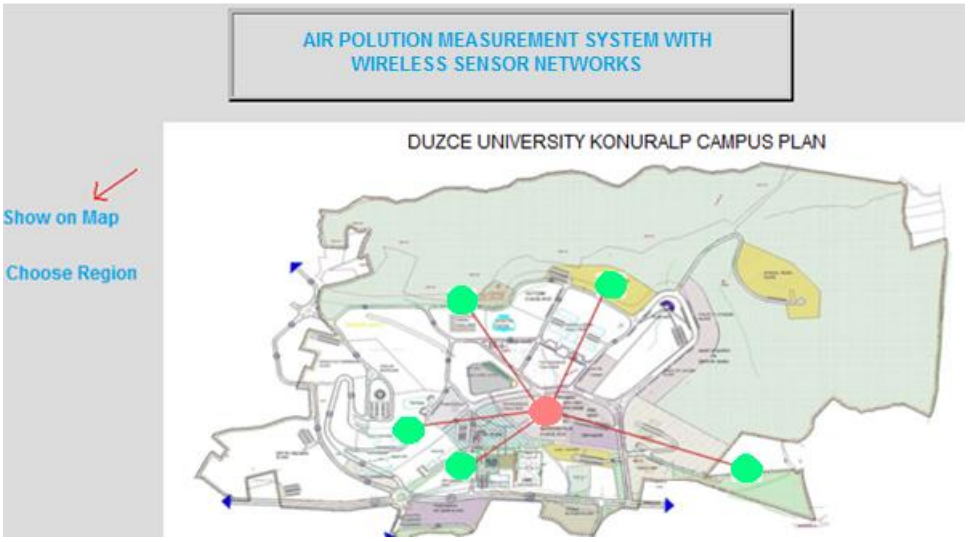

Fig.5. Monitoring of Air Pollution Map of Degree

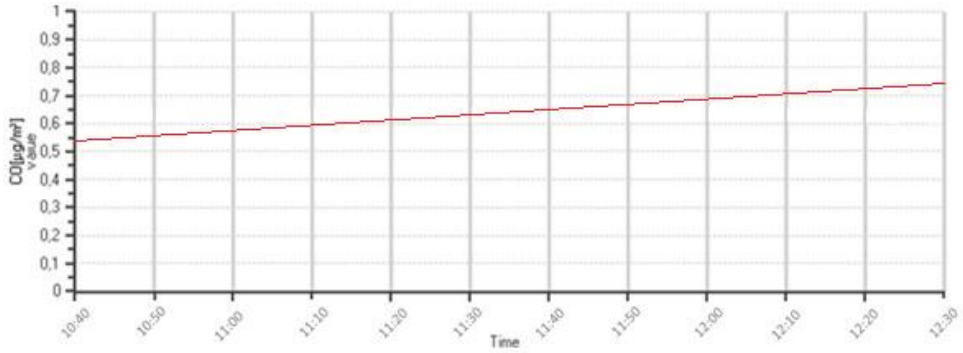

Fig.6. *Measurement results of the developed system*

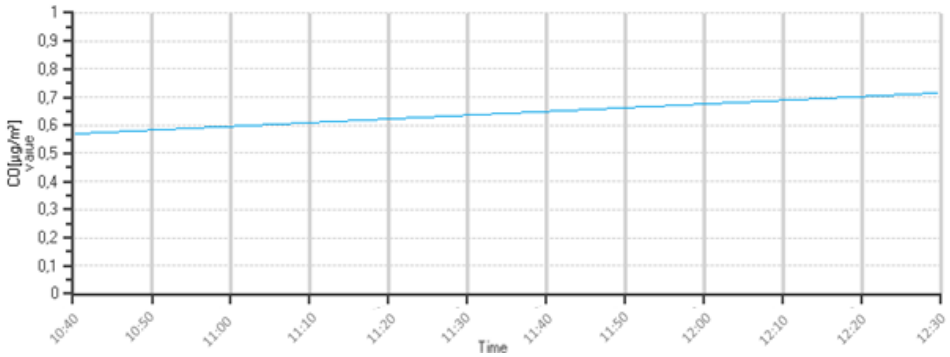

Fig.7. *Air quality rates provided by Ministry of Enviroment and Urbanisation [18]*

Since our study is not a WAN application, it can be thought that using wires can also be efficient.

• Establishing such a wired communication network is harder than establishing such a wireless network. In wireless communication model developed in this study, the only establishment duty is to place sensors into their places. Since the sensors are previously programmed to communicate with base station, there is no need for any other establishment requirement. This programming operation is easier than laying cables to all campus.

• Providing the systems physical persistency is harder in wired communication. Because all cables, which are very long, and the nodes must be hidden not to be injured by environmental effects. But for a wireless model, only the nodes need to be hidden.

• Maintenance of the system in wired communication is difficult since to determine the failure in a meter-long cable is extremely hard. But in case of WSN, not only the measured values but also the names of the corresponding sensors are recorded. Therefore, when a failure occurs, checking the values in the database is enough to figure out the faulty sensor.

• Adapting such a wireless model to another place is easier than the cabled one.

Our contributions to the literature can be summarized as follows:

- A cheaper air pollution measurement system
- A simple interface to follow changes in air quality
- Easier system maintenance via WSN and the software
- Easier establishment and configuration

IV. Conclusion and Future Work

In this study, a ZigBee based system is realized by establishing a WSN. WSN are preferred in this system because of its some properties such as accuracy, reliability, flexibility, cost efficiency, and ease of establishment. Air pollution degree is calculated based on the value of carbon monoxide gas density. The values collected by the developed system and the values taken from the Ministry of Environment and Urbanization are compared. Comparative Results show that both values are very close to each other. Accuracy of WSN is proved so and the expected operation is realized with lower cost.

Other gases (methane (CH_4), isobutane (C_4H_{10}), ethanol (CH_3CH_2OH) and hydrogen (H_2)) whose densities are measured are not evaluated in this study. It can be a subject of a further study by applying the values of those gases. Other sensors with capabilities of sensing different gasses can be used in other applications like natural gas leakage warning systems. Also, the effect of the number of base stations (receiver unit in this application) can be examined and if the effect is negligible when the benefit is thought, then the application can be applied in wide area.

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