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THE OVERVIEW OF THE AIR QUALITY MONITORING BASED ON METAL OXIDE GAS SENSORS AND ZIGBEE TECHNOLOGY

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Abstract. *Air pollution is a major problem for the environmental health, affecting both developing and developed countries. Inhaling pollutants is very harmful for human health, hence, the air quality monitoring is an essential task. The development of the sensor technology and wireless communication has led to the rapid growth of wireless sensor networks (WSN), which present a great technology for detecting, measuring and gathering information from the real world (weather and traffic conditions, air quality etc.) transfering them to end users. Conventional methods of air quality are very expensive and are great consumers of electricity. The alternative to this method are is the WSN systems which have small consumption and are able to receive data on air pollutants in real time. This paper includes the overview of gas sensors and communication technology of WSN for air quality monitoring.*

Key words: *air quality monitoring, wireless sensor networks, gas sensors, ZigBee.*

1. INTRODUCTION

Air pollution is a major problem for the environmental health, affecting both developing and developed countries. The air pollution effects are very complex because there are many different sources with various individual consequences. In any case, inhaling pollutants is very harmful for human health. Recently, the development of good systems for air quality monitoring has been brought to attention, due to the growing reports on health issues caused by bad atmospheric conditions. Detecting air pollutants and determining polluted areas with the aid of monitoring systems are important processes of basic techniques for improving the air quality, such as source control, improved ventilation, air cleaning, etc. [1]. Therefore, measuring the air parameters is an extremely important task, related to the preservation of the environment and health.

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Accordingly, there has been a development of new methods and means to control and monitor air pollution.

Conventional air quality monitoring systems give exact and selective readings of air pollutant concentrations. However, their disadvantages are their high price, large dimensions, electric energy consumption, and spatial limitation. It is for this reason that some of the data on estimating pollutants in ambient air which those systems provide are incomplete. Next, the air quality monitoring systems in the form of compact and handheld devices have space and time limits, since the measuring is performed manually. Portable monitoring stations are also limited in price and covered area. On account of these, the researchers have started developing a system with easily available gas sensors, which have low price and quick response.

The development of gas sensors, communication technologies and wireless sensor networks (WSN) has further enabled the development of efficient air quality monitoring systems which are cost effective and have low levels of energy consumption. Studies have shown that the WSN system, which has a small consumption and can be used for acquiring data on air pollutants in real time, is the alternative to the conventional method of environmental monitoring.

The researches have already developed some air quality monitoring systems based on the WSN technology:

- MAQUMON – mobile monitoring system that uses vehicles which are equipped with sensor nodes for air quality monitoring (O_3, CO and NO2) [16].
- APOLLO – prototype of air quality monitoring system which simultaneously measures concentrations of multiple pollutants (CO, NO_2, PM, CO_2, VOC) [1].
- MESSAGE – British project which resulted in a low-cost air quality monitoring system, with nodes consisting of GSM modules, ZigBee modules, temperature, CO, CO_2 and NO_2 sensors [6].

The majority of wireless networks for air pollution monitoring currently use GSM, GPRS and other technologies. However, their installation and handling are expensive. Even though some authors use ZigBee for purposes of air pollution monitoring, its usage is still not widespread.

This paper includes an overview of gas sensors and ZigBee protocol which could integrate into WSNs for air quality monitoring.

2. Wireless Sensor Network

In recent years, there has been an intensive development of WSNs. Based on this, there have been some devices used for wireless networks of small range, such as Bluetooth and ZigBee wireless local networks, as well as mobile phone systems for greater range, such as GSM/GRPS and CDMA.

The growing development of WSNs was supported by the development in electronic miniaturization (including the microelectromechanical technology systems – MEMS), wireless communications and low consumption rates.

Sensor network is a group of specialized sensors, with communication infrastructure, which was designed for monitoring and recording the conditions at different locations. Sensor network consists of a large number of detection stations, called sensor nodes, which are small in size, light and easily portable, giving great insight into processes that take place inside the physical world. Wireless sensor nodes represent a group of one or more sensors, of different sizes, control units, memories, transceivers, and power sources (see Fig. 1).

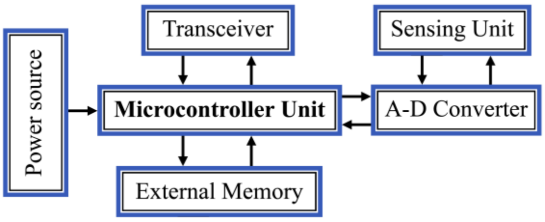

Fig. 1 Basic components of the sensor node [2]

The sensor (sensing unit) generates electrical signals based on the registered physical effects and phenomena. The control unit (microcontroller) processes and stores output data from sensors. The transceiver receives commands from and transfers data to the central computer. When thousands of such nodes are tied, communication is carried out via wireless information exchange and cooperative processing channels, creating the WSN.

In addition to the great number of sensor nodes, WSN also contain basic stations which connect sensor nodes to other networks (see Fig. 2).

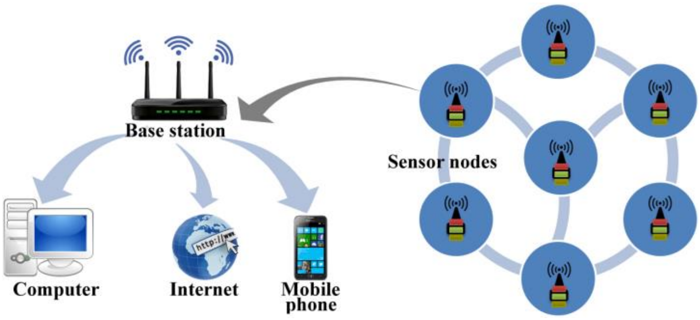

Fig. 2 Wireless sensor network [5]

Some of the advantages of these networks are [8]:

- Self - configuration (sensor network can be distributed over inacessible areas, where human intervention is not possible),
- flexibility and possibility of expansion,
- high sensibility,
- low price,
- exclusion of cables, which enables high mobility and quick distribution,
- effectiveness in hard working conditions,
- large surfaces covered,
- small energy consumption, etc.

WSN is an excellent technology for detecting, measuring and gathering information from the real world and transferring them to end users. Traditionally, it has been used with very high quality systems for detecting radiation and nuclear hazards, as well as with sensors for naval artillery, in biomedicine, for habitat tracking and seismic monitoring. Lately, the usage of WSNs have been recognized in the following fields:

- army – borders monitoring, attacks detection, combat damages estimation, etc.
- health protection – distance monitoring of patients' condition, distance medicine dosage, etc.
- home use – automation of homes, distance control of parameters.
- commercial use – road conditions and traffic congestion monitoring, vehicles monitoring, etc.
- environmental protection – floods detecting, forest fires detection, monitoring of the quality of soil, water, air, etc.

Since health is the main concern of our everyday lives, the system for air pollution monitoring represents a very important tool which could offer:

- current information on the air composition, depending on the user's location,
- simple user interface, available to users everywhere,
- warnings about air pollution via SMS or e-mail for registered users,
- cheap and resistant system for air pollution monitoring.

Functionality of the system can be further expanded by creating personal warnings for users who have an increased sensibility to certain substances.

Conventional approaches to air quality monitoring are limited in terms of time, cost and space. The rapid development of MEMS and WSNs, has made way for developing monitoring systems which are cost effective, with small energy consumption.

Preserving energy in WSNs can be performed by [12]:

- reducing consumption, by selecting micro-control units with small consumption,
- selecting the energy source with low output voltage and small consumption,
- reducing the system's working frequency, which leads to effective reduction of consumption,
- reducing the system voltage, which affects the reduction of system's consumption,
- dynamic consumption control – in case there are no changes in the environment, some nodes could enter sleep mode in order to reduce consumption,
- using solar powered sensor networks, etc.

In general, the development of air pollution monitoring systems with WSN technology will lead to the minimization of installation and maintenance costs, and will enable quick and easy reconfiguration of those systems.

3. Gas Sensors

The basic elements of WSN system for monitoring air quality are gas sensors (Fig. 3).

Fig. 3 Gas sensors [4]

A few physical principles are used in their production. Gas sensors have their advantages and disadvantages, which mainly determine the scope of their application. The basic types of gas sensors which have a practical usage are given in Fig 4.

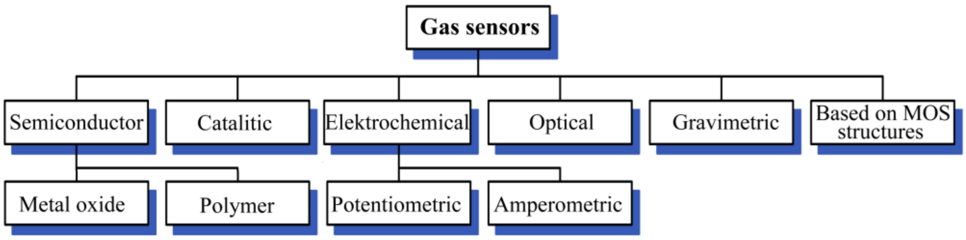

Fig. 4 Basic types of gas sensors [11]

In metal oxide semiconductor gas sensors, various metal oxide materials are used as sensitive materials, such as SnO_2, ZnO, Fe_2O_3, WO_3, Co_3O_4, etc. Their operating principle relies on the increase of conductivity of the sensitive element in the surface area during the sorption of the analyzed gas. Depending on the composition of the sensitive layer, the sensor will react to different gases such as C_2H_5OH, CO, CH_4, H_2, O_2, etc. Operation temperature ranges from 200 °C to 500 °C. Layers based on phtalocyanines, which have high thermal chemical stability are used as sensitive elements in polymer semiconductor gas sensors. These layers are semiconductors of p-type and their conductivity is primarily affected by the oxygen in air. Layer conductivity changes in the presence of gases. Sensor sensibility grows when layers are doped with atoms of heavy metals.

As a result of the ongoing catalytic reactions, heat is generated on the surface of catalytic gas sensor. This heat couses the change in gas sensor temperature, which is measured with temperature sensor.

Electrochemical gas sensors are one of the most universal gas sensors. Depending on their operating principle, electrochemical gas sensors are divided into potentiometric and amperometric. In the construction of each electrochemical sensor there are at least two electrodes (anode and cathode) between which a chemical reaction will occur. Electrodes are made of catalytic metals such as platinum and palladium.

Optical gas sensors are based on mutual actions of the electromagnetic waves and the examined gas, which leads to the alteration of some radiation characteristics, such as intensity, polarization, etc. Optical gas sensors are divided into: optoelectronic sensors, sensors based on optical fibers, ultraviolet and luminescent spectroscopy, infrared and Raman spectroscopy, as well as those based on surface plasmon resonance.

Gravimetric sensors are sensors in which very small mass changes, caused by gas molecules adsorption, lead to the change of mechanical properties of the system. Since there are no chemical reactions, their operating principle is primarily physical. Generators based on piezoelectric crystals are very sensitive to change of mechanical characteristics of the system.

Gas sensors based on MOS- structure, whose metal electrodes are made of transition metals (palladium, platinum, nickel), change their characteristics due to the gas influence.

The aforementioned sensors have their positive and negative aspects, which largely determine in which areas they will be applied. For example, electrochemical sensors (whose elements are in solid state) are used for measuring concentration of oxygen in cars, where

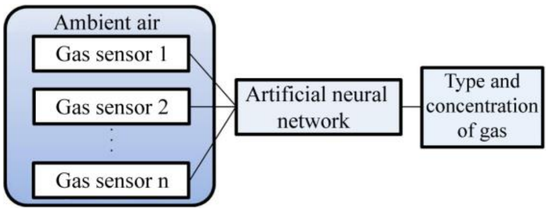

Fig. 5 Scheme of the artificial neural networks usage for gas recognition and concentration determination

emission levels of carbon oxides, hydrocarbon, and nitric oxides are controlled. They are also used in boiler installations for burning control, as well as the control of gas composition in heat treatment in metallurgy, etc. Catalytic gas sensors are found in the industry, primarily for detecting hazardous explosive gases. Optical gas sensors, for example, have high selectivity and sensitivity, and being the most expensive they are used in portable gas analyzers. Metal oxide gas sensors have high sensitivity, low prices and short reaction time and are suitable for developing low-cost air quality monitoring systems. The disadvantage of this type of sensor is its relatively low selectivity and dependency on temperature and ambient humidity, which complicates the gas recognition and concentrations determination. This problem is solved with the aid of artificial neural networks (see Fig. 5) [10].

The leading world manufacturers for metal oxide gas sensors are FIGARO Engineering Inc. (Japan), SYNKERA Technologies Inc. (USA), SGX Sensortech (Great Britain), Sencera (Taiwan), Henan Hanwei Electronics (China), Microsens (Switzerland), etc. The characteristics of the metal oxide sensors manufactuted by those companies are given in Table 1.

Table 1 Characteristics of the metal oxide sensors [3, 13, 14, 15]

Manufacturer	Sensor type	Gas sensitivity	Gas concentration, [ppm]	Power consumption, [mW]
Figaro	TGS2442	CO	50 – 1.000	14
	TGS2444	NH_3	10 – 100	56
	TGS825	H_2S	5 – 100	660
	TGS 2611	CH_4	500 – 10.000	280
	TGS 4161	CO_2	400 – 9.000	300
Synkera	705	NH_3	25 – 10.000	975
	706	NOx	0,5 - 10	500
	707	VOCs	do 100	400
	714	H_2S	1 - 100	900
	711	CH_4, C_3H_8	90 – 10.000	900
SGX Sensortech	MiCS-2714	NO_2	0,05 – 5	50
	MiCS-5524	CO	1 – 1.00	88
	MiCS-5914	NH_3	0,1 – 10	88
Sencera	HS134	CO	do 100	800
	HS811	CO_2	350 – 10.000	1.200
	HS131	CH_4, C_3H_8	1.000 – 5.000	800

4. ZIGBEE™ WIRELESS STANDARD

During the last decade there has been a great progress in the field of wireless communications. Recently, there has been a large number of widely accepted wireless protocols which have found their place in various applications dictated by the market. Most of these protocols' characteristics are high speed of data transfer, consumption which limits the work of such battery charged devices to hours, or eventually days, regular updates of new options and opportunities, which also lead to the increase of memory integration. However, there has been a request for certain standard whose characteristics are completely different than the ones above. The market required a standard which would satisfy the needs for minimum consumption, lower speed of data transfer, the smallest possible memory and low price. The result was that the ZigBee protocol, which took cue from the IEEE 802.15.4 wireless protocol, took over a part of the market which was not adequately covered by other wireless standards.

IEEE 802.15.4/ZigBee represents a global open standard for WSNs, which is used for their monitoring and control. It was developed by ZigBee Alliance. By developing this standard, the following requirements were fulfilled [17]:

- low price
- low energy consumption
- usage of unlicensed band
- cheap and easy installation
- flexibility and wide network, etc.

ZigBee can provide data transfer speeds which are smaller than 1Mbps. The basic advantage of ZigBee is that it can work at the following frequency ranges: 2.4 GHz, 868MHz, 915MHz and with 128-bit encryption technology. ZigBee standard IEEE 802.15.4 enables linking of simple devices which have minimal energy consumption. Therefore, this protocol is applied primarily in sensor systems, where transfer of large amount of data is not necessary, and where it is important that the consumption is so small that sensor batteries can last up to few years. It is very suitable for monitoring, control and automation.

ZigBee networks consist of several types of devices: ZigBee coordinators, ZigBee routers and ZigBee end devices. ZigBee coordinator forms a network root through which a connection with other ZigBee networks can be established. Since the network is initiated by this device, there can only be one ZigBee coordinator in one ZigBee network. ZigBee router acts as a mediator in communication between ZigBee coordinators and other devices in the network. ZigBee end device (which is usually a sensor element, that is, sensor node) possesses sufficient functionality which enables communication with the superior node (any coordinator or router) by their inquiry.

Topology of these networks is as follows: Star typology, Mesh topology, and Tree topology which is considered a special type of Mesh topology (see Fig. 6).

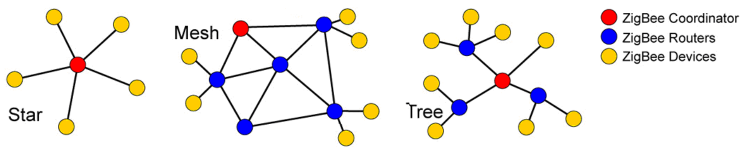

Fig. 6 ZigBee Network Topologies [7]

When it comes to Star type topology, communication is possible primarily between the main device, which has the role of coordinator, and the router or end devices. The plus sides of this topology are its simplicity and the ability for most devices to be end devices (sensor nodes), as well as to be battery charged. Mesh topology is known for its great reliability because there are more possible paths among network nodes, so if one network node should go into standby mode and therefore not be able to participate in the routing, there is a big possibility that another path will be established for communication among nodes. Tree topology combines the advantages of the previous two topologies: the possibility for a bigger number of battery charged devices and bigger reliability.

Table 2 shows the comparison between characteristics of ZigBee standard and other commercial standards for wireless data transfer.

Table 2 Comparison of wireless data transfer standards [17]

Market Name Standard	ZigBee 802.15.4	GSM/GPRS, CDMA/1xRTT	Wi-Fi 802.11b	Bluetooth 802.15.1
Aplication Focus	Monitoring and Control	Wide Area Voice and Data	Web, Email, Video	Cable Replacement
System Resources	4KB-32KB	16MB+	1MB	250KB+
Batery life (days)	100-1000+	1-7	0,5-5	1-7
Network size	64000+	1	32	7
Maximum Data Rate (KB/s)	20-250	64-128+	11.000+	720
Transmission Range (m)	1-100+	1.000+	1-100+	1-10+
Success Metrics	Reliability, Power, Cost	Reach, Quality	Speed, Flexibility	Cost, Convenience

It is an indisputable fact that ZigBee has many advantages compared to other technologies. Some of them are low cost, data transfer reliability, extended battery life, high security, large number of nodes in the networks, route optimisation, ease of distribution, etc. [9].

5. Conclusion

This paper has given an overview of sensors and communication technologies in WSNs for air quality monitoring. The used sensors are small, cheap, intelligent and can be distributed in large numbers. Because of its low energy consumption and simple net configuration, ZigBee is considered the most perspective wireless sensor technology. Sensor networks are largely applied and represent a new field of research which is growing intensively at the moment.

The advantage of these networks lies in the fact that they are self configuring, which means that the sensor network can be distributed in inaccessible areas, or in disaster affected areas where human intervention is not possible.

Flexibility, high sensitivity, low price and the ability for quick distribution of sensor networks create new application areas for remote monitoring and control. In the future, this wide spectrum of application areas will make sensor networks become an essential component of our lives.

Conventional method of air pollution monitoring is the building of stations for air quality monitoring, but this method is very expensive and the collected data do not cover large areas. This is the case with portable stations which are great consumers of electric energy. Based on these studies, it has been proved that the system of WSN, recognized by small consumption and the ability to acquire data in real time, is the alternative to the conventional method of environment monitoring. Therefore, the system integration for air pollution monitoring with WSN technology may reduce the installation expenses and enable quick and easy system reconfiguration for data acquiring and control. This paper will give a clearer insight into how to approach air pollution monitoring in real time, which would eventually lead to the improvement of life quality.

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PREGLED MONITORINGA KVALITETA VAZDUHA ZASNOVANOG NA METALO –OKSIDNIM GASNIM SENZORIMA I ZIGBEE TEHNOLOGIJI

Zagađenje vazduha predstavlja veliki problem po životnu sredinu i zdravlje ljudi koji pogađa zemlje u razvoju i razvijene zemlje podjednako. Udisanje zagađujućih supstanci je štetno po ljudsko zdravlje te je, s tim u vezi, monitoring kvaliteta vazduha izuzetno važan zadatak. Razvoj u tehnologiji senzora i bežičnih komunikacija doprineo je nagloj transformaciji bežičnih senzorskih mreža (BSM), koje predstavljaju odličnu tehnologiju koja može da detektuje, meri i prikuplja informacije iz stvarnog sveta (vremenske prilike, uslovi saobraćaja, kvalitet vazduha i dr.) i da ih prenosi do krajnjih korisnika. Konvencionalni metodi monitoringa kvaliteta vazduha su veoma skupi i veliki su potrošači električne energije. Alternativa ovim metodama su BSM sistemi koji imaju malu potrošnju i koji dobijaju podatake o zagađivačima vazduha u realnom vremenu. U ovom radu je izvršen pregled gasnih senzora i komunikacione tehnologije kod bežične senzorske mreže za monitoring kvaliteta vazduha.

Ključne reči: *monitoring kvaliteta vazduha, bežične senzorske mreže, gasni senzori, ZigBee.*