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Monitoring of CO_2 Amount in Closed Objects via WSN

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***Abstract*—Global warming is big issue of this time. It is caused by producing emissions, mainly carbon dioxide. Many organizations tries to establish restrictions to limit CO_2 emissions. Our aim is to monitor underground parking lots and detect level of carbon dioxide using wireless sensor network. Gained results are drawn in the map of pollution of monitored area.**

***Index Terms*—WSN, CO_2 monitoring, global warming**

I. Introduction

CARBON dioxide is a chemical compound, formed by two atoms of oxide and one atom of carbon connected by two double bonds. Carbon dioxide is a natural part of chemical compounds and atmosphere in certain amount, which is produced by fauna and flora. After the industrialization, carbon dioxide concentration in the air dramatically arose. This fact was caused by gas and oil combustion.

Recently, CO_2 concentration is at such level that population health is at risk. Some animal species can even face extinction because of climatic changes. Carbon dioxide is one of the most typical greenhouse gases and it causes that the heat reflected by Earth surface is kept in the atmosphere. This phenomenon results in increase of Earth temperature, which affects our ecosystem.

According to Kyoto protocol, 141 countries agreed to lower their emissions of greenhouse gases, including carbon dioxide. The aim is to reach 5.2% lower level than concentration of greenhouse gases in the 1990. To control CO_2 level in underground parking lot, its monitoring has to be performed. Nowadays there is a lot of underground parking lots in cities, which are not sufficiently air ventilated. For this purpose wireless sensor network (WSN) should serve [1]. This paper deals with CO_2 detection at the bases of its level monitoring by WSN.

II. Consequences of CO_2 accumulation

In the garages, monitoring of air pollution is provided by measuring the CO_2 level using appropriate sensors which are deployed in whole area, based on the zone division. It is important to deploy sensor all over the building because of different gas concentration in given zones.

Measured values fall in range from 0 to 2 000 ppm (particles per million) CO_2. Minimal carbon dioxide concentration is around 400 ppm which is adequate to clean air. CO_2 is well mixed in the atmosphere, so observations of concentrations from a single site are an adequate indicator of world trends for atmospheric CO_2 [2]. For better imagination, concentration of CO_2 is shown in relative values, where 0% is equivalent to outside air (cca 400 ppm), 100% is adequate to maximal acceptable concentration, usually 2 000 ppm. The air pollution may be divided into several levels. First level is up to 40% which means 800 + 400 ppm, second level is in range up to 65 % which is 13000 + 400 ppm and the third level can get values up to 85% (1700 + 400 ppm). Level of carbon dioxide has a significant influence to the people:

- 1 % concentration of carbon dioxide in the air can cause sleepiness,
- 2 % causes human to be slightly dopey, increases blood pressure and heartbeat and decreases hearing ability,
- 5 % usually stimulate breath center, causes dizziness and confusion and troubles with breathing accompanied by headache and anhelation. This concentration can also result in access of panic.

There are two approaches to detect CO_2 using sensors. The first one is measurement using method of wavelength absorption, which is one of the properties of chemical compound. This method is called NDIR (not dispersive infrared) [3]. The second method is based on changes of electrical charge of chemical reaction measuring. This reaction is a result of air contact (CO_2 particles) with particles in the sensor.

If we want to control and decrease the level of CO_2, at first we need to know its concentration in give area. The most used detection method is using NDIR sensors [4], but the price of sensors is quite high (between 100 and 1000 euro). For that reason we decided to use sensor with technology of measuring chemical reactions. We selected MQ-135 sensor, which provides monitoring of air quality and with suitable settings it can be used as sensor for CO_2 detection.

III. Sensor description

The sensor is designed for the use in air quality control equipments for buildings / offices. It is suitable for detection of NH_3, NO_x, alcohol, Benzene, smoke and CO_2 [5]. The sensitivity characteristic of the MQ-135 sensor can be seen at Fig. 1. This characteristic is used for the conversion of sensors output to the related *ppm* characteristic for the gas under test.

As the graph shows, the CO_2 curve can be described by the equation in the form

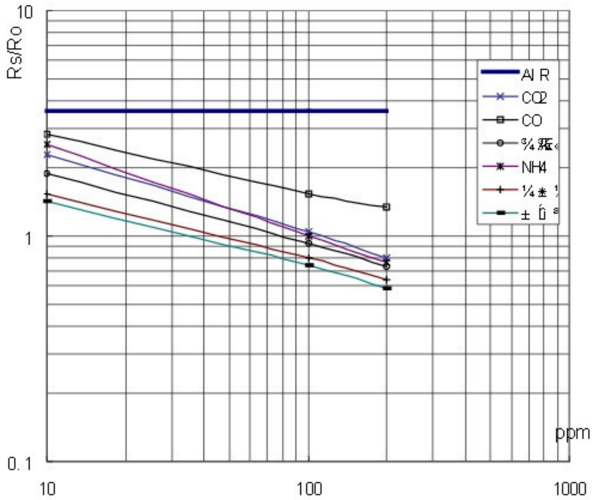

Fig. 1. Characteristics of MQ-135 sensor

$$y = a \cdot x^b, \tag{1}$$

where y corresponds to *ppm* and x corresponds to R_s/R_o.

Since the characteristic is defined graphically, we determine two points that can be described with the minimum deviation. Substituting these points and then solving the set of two equations

$$\begin{aligned} 200 &= a \cdot 0,8^b \\ 10 &= a \cdot 2,1^b, \end{aligned} \tag{2}$$

we obtain coefficients *a* a *b* which represent scaling factor and exponent respectively.

To obtain the calibration constant R_o, known current average value of CO_2 in the atmosphere and the equation 3 is used, where R_s is the measured value, *a = 100.0482*, *b = -3.1041* and current *ppm = 401.52*.

$$R_o = R_s \cdot \sqrt[b]{\frac{a}{ppm}} \tag{3}$$

On this basis, we can conclude that the ppm value can be determined by the equation

$$ppm = 100.0482(R_s/R_o)^{-3.1041}. \tag{4}$$

Using the above calculation, it is possible to obtain values of CO_2 levels in the air of monitored environment. This theory was applied via a wireless network, where each nodes computational part is microcontroller SAM4S.

IV. Description of printed circuit board - processing and communication

The basis of the board is a microcontroller ATSAM4S. This model contains a Cortex-M4 core and it is equipped with RISC architecture. It works at 120MHz frequency, it is equipped with 12-bit AD Converter with Programmable Gain Amplifier and its consumption is 180uA/1MHz-max [6]. The input of the AD converter is a signal obtained from the CO_2 sensor (module with the sensor MQ-135). RF module is also connected to the PCB. Communication between MCU and RFM70 module is provided via SPI communication interface. The sensor node is also equipped with an SD card slot with which the MCU communicates via HSMC interface. The archtecture of WSN node is described at Fig. 2. Sensor, processing and communicational modules are interconnected, so real CO_2 monitoring device can be seen at Fig. 3.

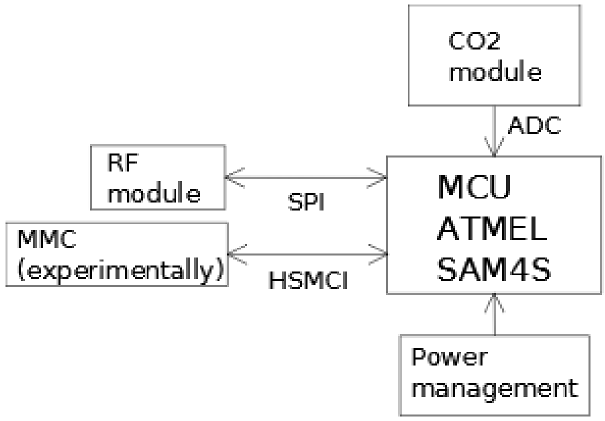

Fig. 2. Architecture of WSN node

A. Collecting the results (processing)

To be able to determine the level of CO_2, it is important to apply mathematical relationship at the output of CO_2 sensor. MQ-135 changes the analog output voltage value with respect to the CO_2 level.

To define this value in digital domain, we use an integrated 12-bit AD converter. After the timer interrupt is set, method $ADCRead()$ is implemented. In this method, a single conversion is performed. When the end of the transfer is reached, the obtained data are stored to the variable and are ready for further processing.

To work with the proper amount of CO_2 level values, it is important to apply the normalization function (4), where we got a correction constant $R_o = 0.869565$, which represents 15% more than measured value. The acquired data are then written to the microSD card (or sent through the RF module) and the MCU waits for the next interrupt from the timer.

WSN node functionality can be divided into several working modes:

- data gathering - sampling, converting signal from analog to digital form (A/D converter), processing, data storage
- data transmission - data encoding, data encapsulation, broadcast
- data receive - filtering, decoding, data extraction, error checking

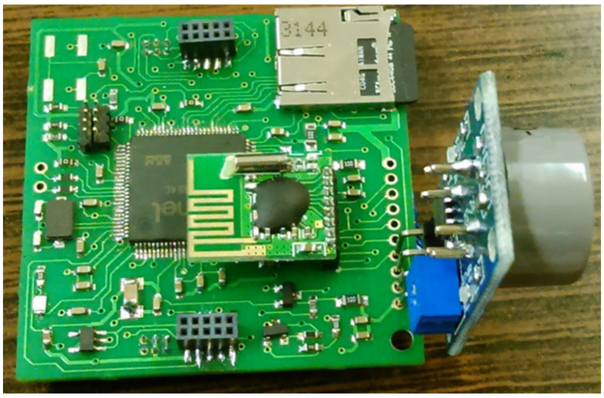

Fig. 3. CO_2 detection module

B. Communication method

When we were creating the network topology, we had to take into consideration some basic information about WSN.

Network designs are based on three types of topologies:

- Bus Topology - This topology consists of a Backbone cable connecting all nodes on a network without intervening connectivity devices.
- Star Topology - In the computer networking world the most commonly used topology in local area networking is the star topology.
- Ring Topology - In ring network, each node is connected to the two nearest nodes so that the entire network forms a circle.

We chose a star topology, which we have expanded to the tree topology. This topology was enough for our purpose of use. Properties of tree topology are:

1) resistance of the network against downtime of the individual stations and lines
2) sensitive to downtime of nodes
3) easy expandability
4) two-point connections

Our next challenge was WSN synchronization. We were deciding between known synchronization methods which are:

- Reference Broadcast Synchronization (RBS), [7]
- Timing-sync Protocol for Sensor Network (TPSN), [8]
- Flooding Time Synchronization Protocol (FTSP), [9]
- Universal synchronization algorithm for wireless sensor networks - "FUSA algorithm", [10]

From these methods, we decided to use the algorithm FUSA, especially because it can be easily implemented and it is not suitable only for hierarchical networks, it is universal and scalable. After resolving these problems, we managed to submit data to the central node and ensure proper network functionality. In the central node, these data are saved on the microSD card. These data are then evaluated in the offline mode, so they can be processed and map of air pollution of the monitored area can be created.

An inexpensive wireless module that meets our requirements is used for communication between nodes. Wireless module RFM70 is a transmitter / receiver that operates at a frequency of 2.4GHz. The module has low power consumption, which is 23 mA when it is used as a transmitter and 18 mA as a receiver. It can be powered by supply from 1.9V to 3.6V, but its inputs withstand the voltage up to 5V. Consumption in standby mode of the module is only 50μA. The speed of wireless transmission of this module is 1Mbps or 2Mbps. The module supports 126 channels. It communicates with the microcontroller via SPI serial interface [11].

Individual nodes are synchronized by FUSA algorithm [10]. Nodes send data via RF module to the central node, where these data are saved on the SD card. These data are then evaluated in the offline mode, so they can be processed and map of air pollution of the monitored area can be created.

V. The deployment of WSN and visualization of results

For testing purposes, WSN was deployed in the basement of the shopping centre [12]. Deployment of the nodes can be seen at Fig. 5, nodes are drawn as black bullets. There was an effort to place the sensors effectively for purposes of measurement. Some of the sensors are placed nearby the doors. Entrances and exits are marked in the figure. Other sensors were placed far from entrance / exit and in the corners where we expected the pollution to reach the highest values. One floor of the underground garage has been diagnosed for the period of one week. The collected data are graphically represented in the Fig. 4, where we can observe the dependence of emissions from the time for the sensor S1, so it is possible to monitor the time trend of the pollution.

Occurrence of emissions in the object during the night and early morning is insignificant (very small) [13]. The rate of pollution increases with active use of the parking lot [14]. This fact is the most visible in the early loading and afternoon emptying of these areas. We noted that the level of emissions for various days is very similar. Friday differs from other days significantly, because parking services are used by most drivers.

Fig. 5 shows the map of the environment with an adequate level of emissions at given time. To create such map, measured emissions from all the sensors that are valid for a given time should be collected. We expected the worst air in the corner areas but on the contrary the most polluted spots were nearby southern exit. We analysed the situation and found out that the cars entering and leaving the parking lot use more often this exit than the eastern exit. It means that on this way, there is often traffic jam while waiting for opening the barrier because each car has to stop and check the parking ticket in the machine and all cars have its engine turned on. Reason for choosing this exit is logistical - this entrance / exit has better connection towards the city centre, other shopping centres and also it is a direction to some apartment settlements. The corner parts are quite good ventilated, what outreached our expectation. That is thanks to effective ventilation system. Thus we can recommend to increase ventilation only in the area of southern exit.

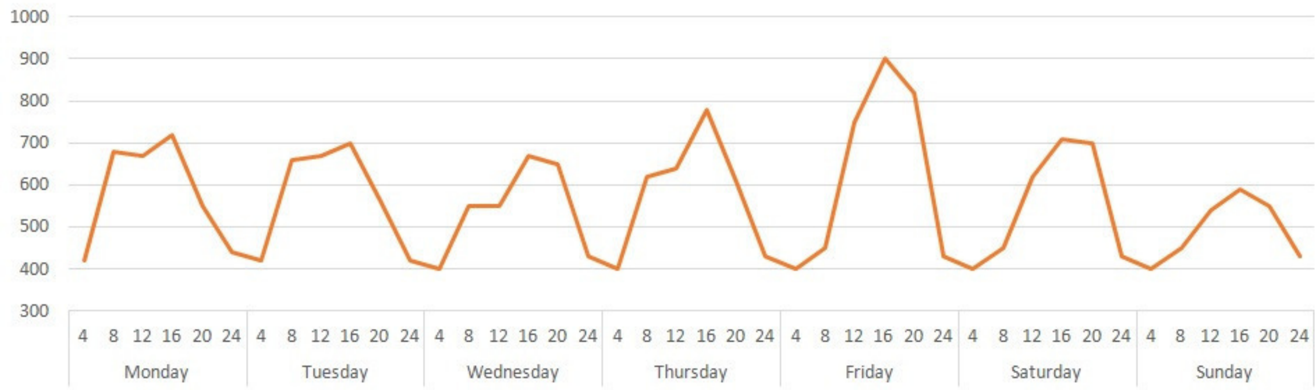

Fig. 4. CO_2 concentration recorded at sensor S1 during the week

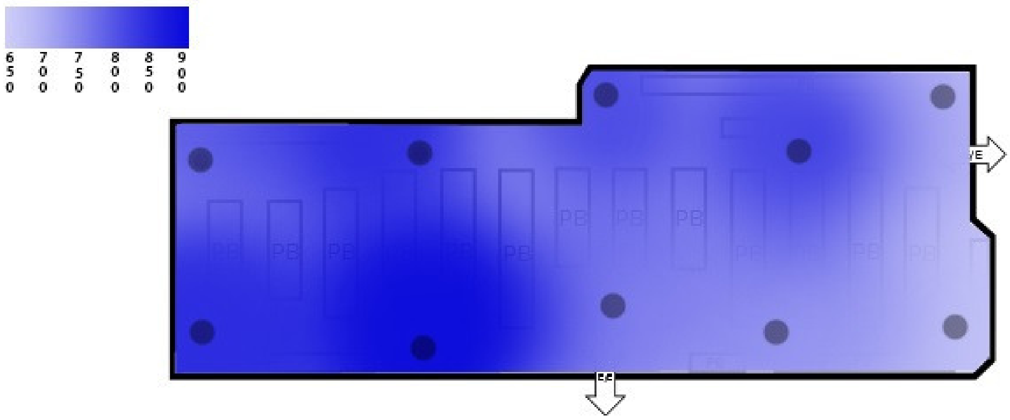

Fig. 5. Map of CO_2 concentration

VI. Conclusion

Underground parking lot monitored during the testing week did not reach the first level of air pollution. This fact is caused by a good ventilation system (air conditioning) deployed in these areas. Nevertheless, it can be said that in the time of rapid usage of these spaces by drivers, the pollution level of parking lot has increased from an average to almost double.

System for the detection of CO_2 proposed and designed by us may be used not only in the underground parking lots but also in industrial zones. In the future, the system could be extended by the microphone and thus it might also serve for measuring acoustic emission eg. at road administration (control of the traffic flow, noise and CO_2 emissions).

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