The Internet of things and indoor air quality on ship

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Abstract. Air quality monitoring is an actively developing area in maintaining a proper environment for people's activity and health. In maritime transport, crews of ships are at constant risk of exposure to hazardous air pollutants, which makes the task of air quality maintenance especially important. The solution proposed in the project - a device for monitoring the air quality in the areas of a ship is developed on the principles of the Internet of Things and uses the latest gas sensors based on microelectromechanical systems. The data collected by the network made of the proposed devices is used for effective control of the ship's heating, ventilation, and air conditioning system.

Keywords: Indoor air quality management, heating ventilation and air conditioning systems, internet of things, merchant ships, carbon dioxide, cognition, decision making, human performance,

1. Introduction
Many confirmations are found for the assumption about the influence of air quality on the labor productivity of personnel at industrial facilities. The modern methods of data acquiring are capable to measure the benefits obtained by maintaining a comfortable working environment. Ambient air quality is just one component that affects staff productivity. Most experts estimate that the average rate of labor performance degradation due to poor air quality is 10% [1].

Indoor air quality (IAQ) can be affected by microbial contaminants (mold, fungus), gaseous pollutants (carbon monoxide, carbon dioxide, volatile organic compounds), dust and aerosols. All of these pollutants can be harmful to humans.

The carbon dioxide is formed people breathe out, and the concentration of $CO_2$ depends on the number of people in the area. Regular researches of the carbon dioxide impact on humans in various conditions show that $CO_2$ affects: the ability to make decisions[2], psychomotor abilities and health [3], the efficiency of personnel [4,5], and so the same long-term presence of personnel in an environment with a constant high level of $CO_2$[6].

The monitoring of $CO_2$ and other parameters are way to make the more effective control of the heating, ventilation and air conditioning (HVEC) systems, obtaining a proper environment and saving energy.

A ship for its crew is not just a workplace, but also it is a crew’s place for the rest and living during a long voyage time (several months), which makes specific demands for the IAQ. About 35% of the world’s merchant fleet are tankers [7]: fuel, gas, and chemical. Almost all types of tanker’s cargo are flammable substances and most types are toxic. The container fleet, with 13% part, can also transport...
flammable and toxic cargo in the tank containers. So the crews of these vessels are under constant risk of exposure to hazardous air pollutants.

Fire alarm systems and closed space gas analysis systems are successfully used on ships. In particular, gas analysis systems make it possible to control the mixture of the atmosphere of enclosed spaces, which ultimately reduces the danger of explosions, discharge of oily water into the sea, saves personnel lives and health on entering closed spaces. All of the above capabilities of these systems reduce the degree of environmental pollution, the possibility of emergencies and incidents on board the vessel, and increase the safety of the operating personnel.

The ship’s HVAC system is usually centralized and managed by zones, which makes it possible to effectively control this system based on IAQ monitoring.

Nowadays, the conception of the Internet of Things (IoT) is spreading more and more - the connection of various small and versatile devices into a network for joint data exchange. An example of such a concept in everyday life is the “Smart Home” technology, in industry it is the robotic production and storage. The IoT way for air quality monitoring in ship spaces involves the creation of a network of autonomous devices for monitoring IAQ. This project is aimed to the development of an air quality monitoring module for working in a network of IoT devices.

Similar projects are proposed by Karami et al [8], Choi et al [9], Rajith et al [10], Dhanalakshmi et al [11]. All of these projects consider working onshore, in buildings, where the most common equipment can be applied, regardless of their energy consumption, size and cost. The use of IoT in transport requires compactness, low power consumption and low cost from the devices.

2. The gases and the sensors

2.1. Gases and its effects on human

The possible composition of gases in ship rooms:

- Oxygen ($O_2$) is a gas vital for the breathing of living organisms, a decrease in oxygen levels to 18-19% causes a fatigue, drowsiness, headaches. Oxygen concentration decrease below the maximum permissible concentration (17%) is dangerous for humans, with 13% of a person loses consciousness, with 7% oxygen, a person dies.

- Carbon dioxide ($CO_2$) is not toxic, but can affect an asphyxily, the normal content of carbon dioxide in the room is 700 ppm, an increase in concentration from 1000 to 2000 ppm causes a person to lose attention, fatigue, loss of performance, headaches. According to the hygienic standards GN 2.2.5.3532-18 [12] for work areas, a one-time maximum permissible concentration(MPC) is 13800 ppm (1.38%), the average monthly: 4600 ppm (0.46%). According to GOST 8050-85 [13] "At concentrations of more than 5%, carbon dioxide has a harmful effect on human health ... At the same time, the volume fraction of oxygen in the air decreases, which can cause the phenomenon of oxygen deficiency and suffocation." The unconscious and death-causing concentration of $CO_2$ is 100000 ppm or 10%. The assessment of the effect of $CO_2$ concentration on the human body according to [3] is presented in the table 1.

- Flammable gases (hydrocarbons), some of these flammable gases can be toxic, suffocation occurs at 25-30% concentration, however, their explosion hazard is a much danger, which arises (for example, for methane) from 4.4% to 17% of the gas concentration.

- Toxic gases such as carbon monoxide ($CO$), hydrogen sulphide ($H_2S$) are poisonous gases that cause poisoning in humans. MPC of carbon monoxide according to [12] 17.5 ppm (0.0017%), concentration in the air of more than 0.1% (1000 ppm) leads to death within an hour. MPC in the working area according to [12] 7.2 ppm (0.0007%), concentration of more than 0.1% (1000 ppm) leads to death within 10 minutes

Based on the listed features of the gases presented, there are two conclusions:
Detection of even small concentrations of toxic and explosive gases is a guarantee of the safety of the crew.

Indoor air quality is determined by the concentration of oxygen and carbon dioxide, and the concentration of carbon dioxide is actually the main indicator of the state of the air (more carbon dioxide - more other harmful substances), since the effect of an increased level of carbon dioxide affects before the lack of oxygen. In general, the concentration of $CO_2$ requires constant monitoring in rooms where people are staying, in particular on transport.

2.2. Gas sensors

The electronics industry today offers a wide range of energy-efficient and cost-effective sensors for detecting a variety of gases. In addition to gases, sensors could be divided according to sensing technology [14], which determines the energy efficiency and price of the sensor:

- Catalytic sensors: cheap, energy inefficient, less reliable technology.
- Electrochemical sensors: expensive, energy efficient, but low lifespan technology.
- Optical sensors: expensive, power dependant, but very reliable technology.
- Semiconductor sensors: cheap, energy inefficient and reliable technology.
- Micro-electromechanical systems (MEMS) sensors: cheap, energy efficient, most miniature technology.

### Table 1. Effects of carbon dioxide in indoor air

| $CO_2$ concentration | Psychological change | Psychomotor performance | Health symptoms |
|----------------------|----------------------|-------------------------|----------------|
| > 500 ppm            | Symptoms from Symptoms from the cardiovascular system | Sensible symptoms above 700 ppm |
| > 1000 ppm           | Cognitive performance lowering | Respiratory symptoms |
| > 10000 ppm          | Increased respiratory rate, respiratory acidosis, metabolic stress | Decreased exercise tolerance in workers |
| > 30000 ppm          |                                      |                         |
| > 50000 ppm          |                                      |                         |
| 80000-100000 ppm     |                                      |                         |
| > 100000 ppm         |                                      |                         |
The usage in the IoT systems, a gas sensor must have the following parameters: low power consumption, low price, small dimensions and long lifespan, taking into account these parameters, MEMS gas sensors are the best option.

There are several types of oxygen sensors suitable for measuring the $O_2$ concentration in the atmosphere: electrochemical and optical, both types are not very suitable for IoT systems, but the detection of the indoor oxygen concentration is not so significant parameter for assessing the quality of the atmosphere. The concentration of the $CO_2$ level could be used as indicator of the content of other more harmful pollutants and the corresponding ventilation rate. $CO_2$ sensors are of the following types: semiconductor, optical, MEMS - sensors. Combustible and toxic gas sensors are optical, catalytic, semiconductor, and MEMS. Therefore, to determine the air quality in most ship spaces, it is sufficient to use in one device a combination of two or three MEMS sensors: $CO_2$ and combustible gases or $CO_2$, combustible and toxic gases.

3. The prototype

The figure 1 represents the block diagram of the IoT module for measuring indoor air quality. The MEMS sensors are the miniature SMD components and the sensor output signal is depend on the gas type or sensor manufacturer, can have either analogue or digital output. In the first case, the sensor should become a part of the measuring circuit for normalizing the output signal for further analog to digital conversion. If the output of the sensor is digital, then the sensor is simply connected to the microcontroller through the appropriate interface.

![Figure 1. The block diagram of indoor air quality IoT module](image)

Suitable models of sensors for detecting flammable and toxic gases are Wisen GM-402B, GM-702B. These sensors is using MEMS micro-fabrication hot plate on a $Si$ substrate base, gas-sensitive materials used in the clean air with low conductivity metal oxide semiconductor material. When the sensor exposed to gas atmosphere, the conductivity is changing as the detected gas concentration in the air. The higher the concentration of the gas, the higher the conductivity.[15]

$CO_2$ sensor Infineon XENSIV PAS 210 is based on the method of photo-acoustic spectroscopy. The method uses the rotational and vibrational states of molecules excited by IR pulses of light and absorbed energy, which form an acoustic wave captured by a MEMS microphone[16].

The microcontroller included in the module acquires data from the sensors and prepares them for sending to the local network. The microcontroller must be energy efficient. The network interface of the module can be either wired or wireless; the main requirement for the network interface is also energy efficiency. A suitable programmable controller with energy efficient MCU and network interface is the Arduino Nano 33 IoT. It has next characteristics:

- Cortex-M0 32-bit SAMD21 MCU.
- u-blox NINA-W102 network interface with Wi-Fi and Bluetooth Low Energy.
- 14 digital I/O pins.
- 8 Analog input pins.
- UART, SPI and I2C communication interfaces
- Input operation voltage for built-in LDO up to 21V;
- Maximum energy consumption with network usage on Wi-Fi is about 120 mA; on BLE is about 50 mA.

In addition there are some power supply is required:
- For heaters of combustible and toxic gas sensors: 2.8 V;
- For CO₂ sensor and Arduino power input (Vin) : 12 V;

The proposed IAQ measurement IoT module characteristics is presented in table 2 absorbed energy, which form an acoustic wave captured by a MEMS microphone.

The IAQ modules should be installed in the ship areas with permanent or frequently crew presence like: cabins, mess rooms, galley, central control room, bridge, engine room, cargo control room, workshops, etc.

| Characteristic                                      | Value                  |
|-----------------------------------------------------|------------------------|
| Maximum current consumption of NANO 33 IoT          | 120 mA                 |
| Maximum current consumption of XENSIV PAS 210      | 10 mA                  |
| Maximum heater current consumption of Winsen GM-402B and GM-702B | 30 mA                  |
| Maximum measuring current consumption of Winsen GM-402B and GM-702B | 0.3 mA                 |
| Summary current consumption                        | 190.6 mA               |
| Detectable gases                                    | CO₂, CO, C₃H₈, C₂H₅, H₂ |
| Measuring range for CO₂                             | 0…10000 ppm            |
| Measuring range for CO                              | 5…5000 ppm             |
| Measuring range for C₂H₅                            | 1…10000 ppm            |
| Network interfaces                                  | Wi-Fi, Bluetooth low energy |
| Working range                                       | > 100 m                |

The data, gathered by modules, collected via the IoT network to the ship server, where it visualized and used for ship HVEC automated control. The figure 2 shows the render of IAQ module prototype. The figure 3 illustrates the structure of IoT network.

![Figure 2. The IAQ module prototype](image)
4. Conclusion
The prototyped IoT module could be supplemented with other kinds of sensors, such as temperature or humidity, that make possible to increase the efficiency of the ships HVEC control. Making the module meet the Ex standards it could be used in closed spaces, and in spaces adjacent to oil tanks. Alternative usage of this IoT approach is the environmental monitoring on sea transport.

The monitoring of an air quality on sea transport could improve the efficiency and safety of crew members, which reduces potential risks and expenses. An Internet of Things concept application on sea transport makes air quality monitoring simple and cost-effective for ship owners and ship operators.

References
[1] Berner Alifio 2000 Indoor air quality AVOK Vent. Heating, Air Cond. Heat Supply Build. Therm. Phys. 5 12–9
[2] Satish U, Mendell M J, Shekhar K, Hotchi T, Sullivan D, Streufert S and Fisk W J 2012 Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance Environ. Health Perspect. 120 1671–7
[3] Azuma K, Kagi N, Yanagi U and Osawa H 2018 Effects of low-level inhalation exposure to carbon dioxide in indoor environments: A short review on human health and psychomotor performance Environ. Int. 121 51–6
[4] Jurado S R, Bankoff A D P and Sanchez A 2014 Indoor Air Quality in Brazilian Universities Int. J. Environ. Res. Public Health 11 7081–93
[5] Allen J G, MacNaughton P, Satish U, Santanam S, Vallarino J and Spengler J D 2016 Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments Environ. Health Perspect. 124 805–12
[6] D J L M, Watkins S, D D A M and Surgeon F 2010 In-Flight Carbon Dioxide Exposures and Related Symptoms: Association, Susceptibility, and Operational Implications
[7] United Nations 2020 Review of Maritime Transport 2020 (New York, NY, USA: United Nations Publications)
[8] Karami M, McMorrow G V and Wang L 2018 Continuous monitoring of indoor environmental quality using an Arduino-based data acquisition system J. Build. Eng. 19 412–9
[9] Choi M, Cho K, Hwang J Y, Park L W, Jang K H, Park S and Park S 2017 Design and implementation of IoT-based HVAC system for future zero energy building 2017 IEEE
International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops) pp 605–10

[10] Rajith A, Soki S and Hiroshi M 2018 Real-time optimized HVAC control system on top of an IoT framework 2018 Third International Conference on Fog and Mobile Edge Computing (FMEC) pp 181–6

[11] Dhanalakshmi S, Poongothai M and Sharma K 2020 IoT Based Indoor Air Quality and Smart Energy Management for HVAC System Procedia Comput. Sci. 171 1800–9

[12] Popova A Y 2018 Maximum permissible concentration(MPC) of harmful substances in the air of the working area

[13] Maximov M I and Vlasova O N 2008 GOST 8050-85: Gaseous and liquid carbon dioxide. Specifications (Moscow: Standartinform)

[14] Liu X, Cheng S, Liu H, Hu S, Zhang D and Ning H 2012 A Survey on Gas Sensing Technology Sensors 12 9635–65

[15] Winsen 2017 GM-402B MEMS Combustible Gas Sensor Winsen

[16] Hicham R 2020 CO 2 Sensor Helps to Reduce the Risk of Covid-19 Transmission Indoors EETimes Eur. 13–8