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Automation of monitoring of background radiation and hazardous gas emissions from coal waste dumps using UAV and wireless sensor networks in combat conditions

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Abstract. To date, the relevance of the issue of automated greenhouse gases monitoring on coal heaps in combating armed aggression of the Russian Federation is given a priority in connection with a significant potential threat to the environment and safety of life living in the surrounding areas. In the case of rockets and aviation, which means the defeat of the breed of coal mines, there is an increase in the risk of damage to units and parts of the armed forces in these territories. The analysis of publications in the area of automation of dangerous gases with the use of air surveillance shows that the use of UAVs for these tasks in the conditions of hostilities can reduce the risks for the personnel of the units of the RCB protection and operational and rescue units of the SES. The rapid technological development of monitoring automation tools has identified a number of tasks to solve, which will be effective in combining UAVs and wireless networks to monitor the emissions of hazardous gases. This task can be solved with mini and micro UAVs, stationary surveillance posts, and mobile MECH networks, which are currently complex and systematic but still not effectively resolved. The work presents the components of the developed automated system of monitoring emissions of dangerous gases from coal blades and substantiates its composition, system of information processing, and transmission of information to data processing centers. According to the results of the publication, recommendations for the formation of the composition of sensors, types of mini and micro UAVs, and the use of a developed complex of technical, organizational, and tactical measures to monitor coal breed dumps are proposed.

Keywords: coal waste dump, monitoring system, automation, air surveillance, mini and micro UAVs, dangerous gases.

Introduction

Problem statement. Ukraine ranks first in Europe in terms of geological coal reserves. Coal mining takes place in three regions: the Donetsk and Lviv-Volyn hard coal basins and the Dnipro lignite basin. The total area of these basins is 18.000 km^2 – it is 3% of the area of our homeland.

There are 1220 coal waste dumps on the territory of Ukraine. In Donbas, there are 1,185 waste heaps, 397 of which are burning. The total area covered by burning waste heaps in Ukraine reaches 80,0 km^2, including 72,0 km^2 in Donbas. Strikes on waste heaps during armed hostilities can lead to death or damage to various functional systems of the bodies of Ukrainian Armed Forces (UAF) personnel and the residents living in the surrounding area.

Since the beginning of Russia's hybrid war against Ukraine, underground water flooding has been occurring at mines in the Donetsk and Luhansk regions controlled by separatists. Subsidence of soil and the contamination of drinking water with radioactive elements are consequences of the lack of environmental monitoring of abandoned mines and waste heaps.

Literature review

According to a number of recent studies, during self-heating, one ton of coal waste can generate 0,84 kgs of SO_2, 0,61 kgs of H_2S, 0,03 kgs of NO_x, 99,7 kgs of CO, and 0,45 kgs of smoke. Each year, one waste heap releases 15.000 tons of CO_2 and 5.000 tons of CO into the atmosphere [1]. Dust emitted from the waste heap contributes to the development of cancer and can lead to various diseases of the central nervous and circulatory systems, kidneys, and liver. Aside from this continuous impact, the operation of such waste heaps can lead to a technogenic catastrophe, such as the explosion of a waste heap in the town of Dymytriv (now Myrnohrad). Approximately 50% of the gas emitted from waste heaps is methane; carbon dioxide accounts for about 45%, with the remainder consisting of nitrogen, oxygen, hydrogen, and other gases. The global warming potential of methane is 21 over a 100-year period [2]. This means that one kilogram of methane is 21 times more potent than one kilogram of carbon dioxide in causing climate change over a 100-year period.

These facts emphasize the necessity to research in this area, especially considering that in Ukraine, there is no specialized research on monitoring coal waste heaps and spoil tips using UAVs and wireless sensor networks [3].

Furthermore, these works typically do not discuss the military-technical aspect of evaluating technical solutions for monitoring waste heaps using modern technical means based on IoT technology, which, according to the "effectiveness-cost" criterion, provides a significant increase in the efficiency and objectivity of monitoring these hazardous objects [4].

The aim of this publication is to introduce promising technological solutions based on IoT technology with the use of UAVs in terms of developing an information-analytical system for monitoring hazardous gas emissions in the combat zone from coal mine spoil heaps to enhance the level of military-technogenic safety of the Ukrainian Armed Forces.

Materials and Methods

The results of the analysis conducted and presented in the monography [3] revealed that the only state documents regulating the rules for the operation of coal waste dumps are:

1. The Rules for Occupational Safety during the Development of Mineral Deposits by Open-Cut Mining (Decree No. 61 of March 18, 2010, by the State Committee of Ukraine for Industrial Safety, Occupational Safety, and Mining Supervision);

2. Rules of Safety in Coal Mines (Decree No. 62 of March 22, 2010, by the State Committee of Ukraine for Industrial Safety, Occupational Safety, and Mining Supervision).

According to paragraph 8.5.6 of the Rules of Safety in Coal Mines, to prevent, control, and extinguish fires in coal waste heaps, A list of necessary actions has been established, formulas for calculating the mechanical protective zone of the heap have been outlined, the timeframes for checking the waste heaps have been defined, and their classification according to temperature has been determined.

However, no information has been provided about the means for determining the geophysical parameters of the waste heap. There is also the overly concise definition of waste heap monitoring. At the state level, there are no methodological recommendations for environmental monitoring of waste heaps and determining the composition of natural-technogenic hazards associated with their operation. Additionally, there is no clear regulation for the monitoring tools.

For instance, thermal imaging surveys of waste heaps are conducted by private organizations. According to paragraph 8.5.6 of the Rules of Safety in Coal Mines, temperature measurements on active waste heaps that are burning are taken three times a year (in May, July, and September). On the inactive waste heaps that are burning, temperature measurements are taken once a year (in August or October).

The results of the surveys on near-surface methane emissions in the "Pervomayskvuhillya" mining fields (the supervisor Perepelytsa B.O. [3]) showed that in case of regional flooding of mines, the frequency and area of methane gas measurements should be increased, especially within of cities, towns, and villages, as well as industrial sites near critical infrastructure objects (see Fig. 1).

Generally, the results of the conducted rapid atmospheric methane studies in 2022-2023, despite their preliminary nature, indicate the urgent need to improve monitoring and the assessment of the environmental impact of coal waste heaps under conditions of regional mine flooding and increased ground-level methane emissions during intense combat operations.

To prevent (minimize) the occurrence of negative phenomena and processes associated with waste heaps, constant geoecological monitoring is necessary. The efficiency of solving problems in the coal mining areas, particularly the processes of combustion in spoil heaps and waste piles, can be increased by using Earth remote sensing (ERS) data and the application of aerial reconnaissance using UAVs equipped with thermal cameras and hazardous gas sensors.

The control of the thermal state of the waste heaps can be carried out using the following means:

1. Photographic surveying. Currently, low-altitude infrared aerial photogrammetry is among the most popular methods for collecting thermal data. Satellite imagery and UAV remote sensing help effectively address issues in the coal mining industry related to the combustion processes of spoil tips and waste heaps.

2. Thermal imaging examination with a pyrometer. Thermographic imaging is carried out using thermal imagers. The temperature survey of rock dumps is carried out in accordance with the requirements of clauses 7.2. and 7.3. "Instructions for preventing self-ignition, extinguishing and disassembling rock dumps"

3. Well monitoring. In this method, measuring devices for continuous monitoring of thermal parameters are installed in the dump mass using depth drilling.

4. Radioactive method. Sedimentary rocks contain radioactive elements such as uranium (92U235, 92U238), thorium (90Th232). These radioactive elements emit α-particles during decay. During this process, they are converted to radon (86Rn222, 86Rn220, 86Rn219) with a half-life of 3.96 seconds to 3.825 days. The measured concentration of α-particles depends on the temperature, that is, if the temperature is higher, the transport of α-particles is higher.

5. Measurement of resistance. Rock resistivity is calculated using several electrical poles by

measuring the resistance in ohms (Ohm) per meter and comparing it to a standard value. Under normal conditions, the resistivity of sedimentary rock is 600-800 Ohm/m, but in burnt rock it increases to 1200-3000 Ohm/m, due to high porosity, cracks and low water content.

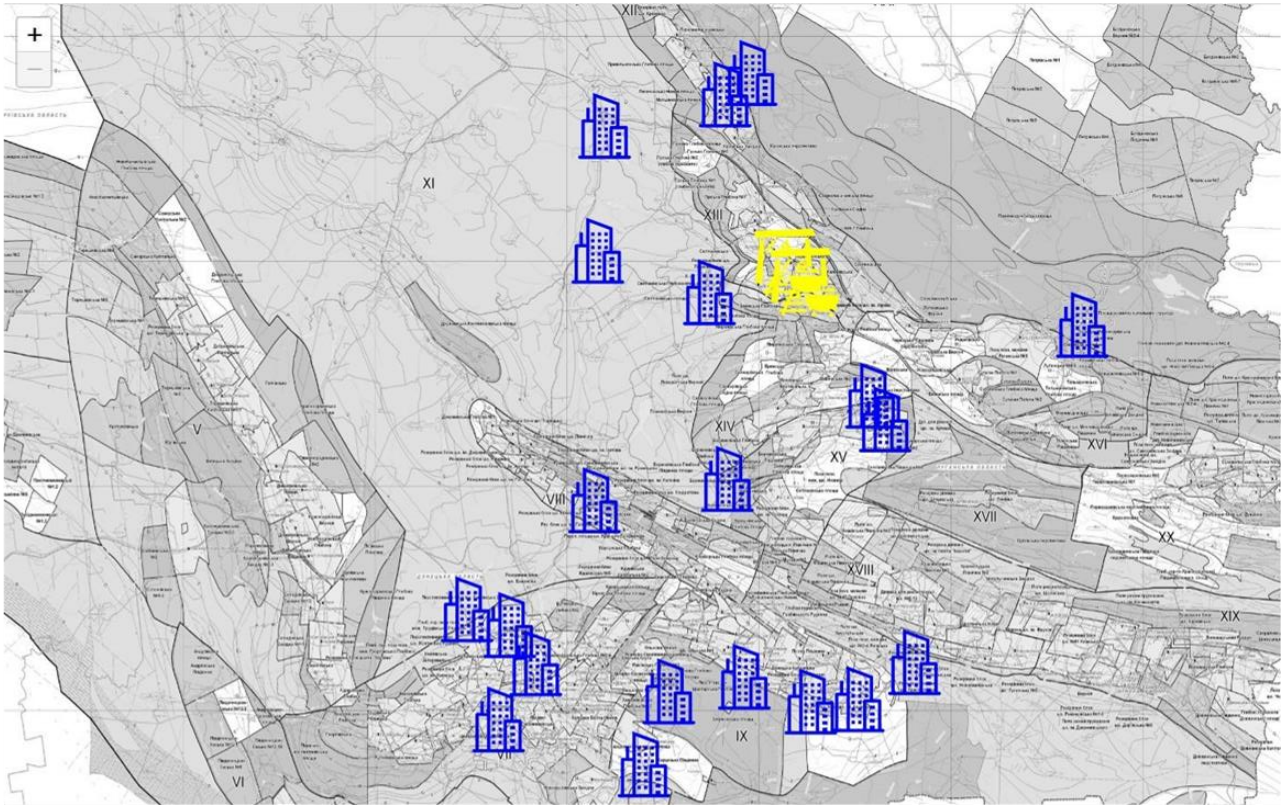


Figure. 1. Flooding and methane emissions in the territory of the Pervomaisk coal mining region of Donbas [3]

It should be noted that today there is no ready-made methodology for comprehensive fire and explosion safety monitoring of the Tericons of Donbas, therefore there is a need to carry out scientific work and develop an effective and modern environmental monitoring system using innovative technologies of unmanned aerial vehicles and IoT.

Analysis of the use of UAVs for monitoring coal rock dumps

Earth remote sensing (ERS) — observation of the Earth's surface by aircraft (planes, rotorcraft, UAVs) and space means (satellites), equipped with various types of filming equipment.

The application of ERS for monitoring the fire and explosion hazard of coal rock dumps in the condition of the current increase in methane inflows into the surface atmosphere as a result of the regional flooding of mines in all coal mining areas of Donbas[3] can become a reasonable alternative to existing means due to a number of factors.

First of all, conventional fire detectors (usually these are automated fire alarm systems) are not quite suitable for a number of reasons: the large area of the necessary coverage, the need for technical support, specialization, and it is impossible and impractical to cover a large area of the forest or field with them. However, thanks to IoT, it became possible to create a wireless sensor networks (WSN), which will, by collecting data from sensors, notify the relevant services about an emergency situation around a potentially dangerous object.

Secondly, in such areas, the most common method of fire detection is the contact method (when persons who are directly near the fire place inform the State Emergency Service about the

burning). The process takes precious time and it is not a fact that the informant will be at the very beginning of the ignition, and not at the moment when the fire starts to spread.

Another, fundamentally different, group of information gathering methods is based on the data of remote sensing of the Earth, which is carried out using UAVs, airplanes or artificial satellites of the Earth. Earth remote sensing satellites can be placed both in heliostationary orbit (they scan the Earth twice a day) and in geostationary orbit, in which the scanning period can be 2.5 min [5].

Among the positive factors are the following:

1) Economic efficiency.

Unlike other methods of observation (use of UAVs, thermal imaging examination with a pyrometer), in this case there is no need to constantly be near the fire. To start monitoring, you can choose any place, install equipment and conduct observations from one position for as long as you want.

2) Scalability.

The capabilities of photoelectronic equipment of satellites, in particular NASA probes, allow to cover the entire country, or a significant part of it, unlike other methods, which require constant monitoring of a potentially dangerous object.

Among the negative factors are the following:

1. Complexity of software development. Detecting fires in pictures manually is a useless solution. Software requires calculations: a number of factors should be taken into account for research. For example, you can take calculations for fire detection on satellite images of the Landsat, ASTER series. Even partial sunlight significantly disturbs the obtained temperature values [5].

2. Inaccuracies of the fire detection algorithm:

First, the minimum heat emission power for its fixation by the satellite's thermal scanner is 0.2 MW (200 kW). That is, the system will not record a bonfire lit in the field.

Secondly, only infrared waves emitted in the direction of the satellite are recorded. Therefore, satellite sensors will not always detect smoldering landfills, peatlands, terricones, burning forest litter.

Thirdly, heat emissions are recorded only when the satellite flies over the territory. Yes, the NOAA 20 satellite makes a complete revolution around the Earth once every 101.44 minutes, and a good signal can be received when the satellite is high above the horizon. This time for Ukraine comes at 03:47 and 13:22 and lasts for 10 minutes, so there is a need to prepare for the communication session in advance.

As practice shows, a UAV or UAV is a fairly versatile tool for solving a variety of tasks. The war in Donbas once again proves that the use of modern devices of this category when using appropriate software significantly increases the effectiveness of many types of monitoring in the combat zone.

For the performance of special tasks, in particular for aerial photography of gas methane and thermal flows of coal-fired tericons as fire-explosive objects, it is advisable to consider UAVs together with their equipment and payload, for which the term "unmanned aerial system" (UAS) was introduced. The payload for aerial photography tasks includes a digital camera, video camera, thermal imager, infrared camera, and hazardous gas sensors can be used as additions.

They are entrusted with the task of monitoring the temperature and gas condition (fire regime) of the tericon. Since the coal dump complex occupies a relatively small area (the size of the tericon is < 0.37 km^2) [4], the use of UAVs with a medium range will be the most economically beneficial and effective.

The most popular medium UAVs include:

1) Syma X5SW 95 Technical characteristics: control via radio channel, control range up to 150 m. The battery with a capacity of 500 mAh allows flights lasting up to 5.5 minutes. Weight – 1216 g. The camera is external in the set, the matrix expansion is 2 MP, the video recording resolution is 720p.

2) DJI Phantom 3 Standard Technical characteristics: maximum flight height - 6 km, maximum flight speed - 16 m / c, built-in GPS sensor, control via radio channel, there are functions of autopilot, following the operator, return to the take-off point, control range up to 1 km, Wi-Fi. The battery with a capacity of 4480 mAh allows flights lasting up to 25 minutes. Weight – 1216 g. Camera: external included, 12 MP matrix expansion, 94 ° viewing angle, video resolution – 1080p, photo resolution 4000x3000.

3) DJI Phantom 3 Professional Technical characteristics: maximum flight height - 6 km, maximum flight speed - 16 m/s, built-in GPS and GLONASS sensors, control via radio channel, there are autopilot functions, following the operator, return to the take-off point, control range up to 2 km, Wi-Fi. The battery with a capacity of 4480 mAh allows flights lasting up to 23 minutes. Weight – 1280 g. Camera: external included, matrix expansion – 12.4 MP, viewing angle 94°, video resolution – 4K (2160p), photo resolution – 4000x3000.

4) DJI Phantom 4 Technical characteristics: maximum flight height - 6 km, maximum flight speed - 20 m/s, built-in GPS and GLONASS sensors, control via radio channel, there are autopilot functions, following the operator, 96 return to the take-off point, evasion system from obstacles, control range - up to 3.5 km, Wi-Fi. The battery with a capacity of 5350 mAh allows flights lasting up to 28 minutes. Dimensions: 289.5x289.5x196 mm, weight - 1380 g. Camera: external included, matrix expansion 12.4 MP, viewing angle - 94°, video recording resolution - 4K (2160p), photo resolution - 4000x3000.

5) DJI Phantom 4 Pro Technical characteristics: maximum flight height - 6 km, maximum flight speed - 20 m/s, built-in GPS and GLONASS sensors, control via radio channel, there are autopilot functions, following the operator, return to the take-off point, control range - up to 3.5 km, Wi-Fi. The battery with a capacity of 5870 mA makes it possible to fly for up to 30 minutes. Weight – 1388 g. Camera: included external, 20MP matrix expansion, 84° viewing angle, video resolution – 4K (2160p), photo resolution – 5472x3648.

Analysis of the use of WSN for monitoring coal rock dumps

The WSN method is essentially an IoT-modified method of standard temperature measurement at a depth of 0.1; 0.5; 1.5 and 2.5 m.

The modification consists in increasing the depth of taking soil samples for thermal analysis and installing additional data collection and transmission modules. Interaction between devices takes place by means of radio communication of different frequency ranges. The most effective in terms of efficiency in terms of energy consumption\packet transmission is the radio channel on ultra-short waves - VHF, which is used in the Internet of Things (IoT).

It is impossible not to see the positive aspects of using IoT technology, because IoT allows users to receive data from devices and use them to perform one or another task, for example, to diagnose equipment in hard-to-reach places. In this case, this approach allows you to reduce the number of people leaving, save money, and at the same time reduce the risk of injury.

During the analysis of possible options for building an information system for monitoring environmental parameters in the zone of influence of potentially dangerous objects in Donbas, a decision was made to build a universal monitoring system to work with both radio communication and the Wi-Fi network.

The system must work on a wireless channel, and therefore must have a sufficient coverage area for device communication and/or use the coverage area of other networks (including Wi-Fi for communication and data transmission).

The system must remain for a long time without recharging, and this requires a low supply

voltage (up to 5V).

To use a Wi-Fi network, the NodeMcuV3 Wi-Fi module or Ethernet Shield is quite suitable. ESP8266 will be the main microcontroller.

MQ135 is perfect for detecting dangerous gases, because although it is not so powerful for accurate detection of the content of substances, it is 10 or even 20 times cheaper than the most powerful analogues.

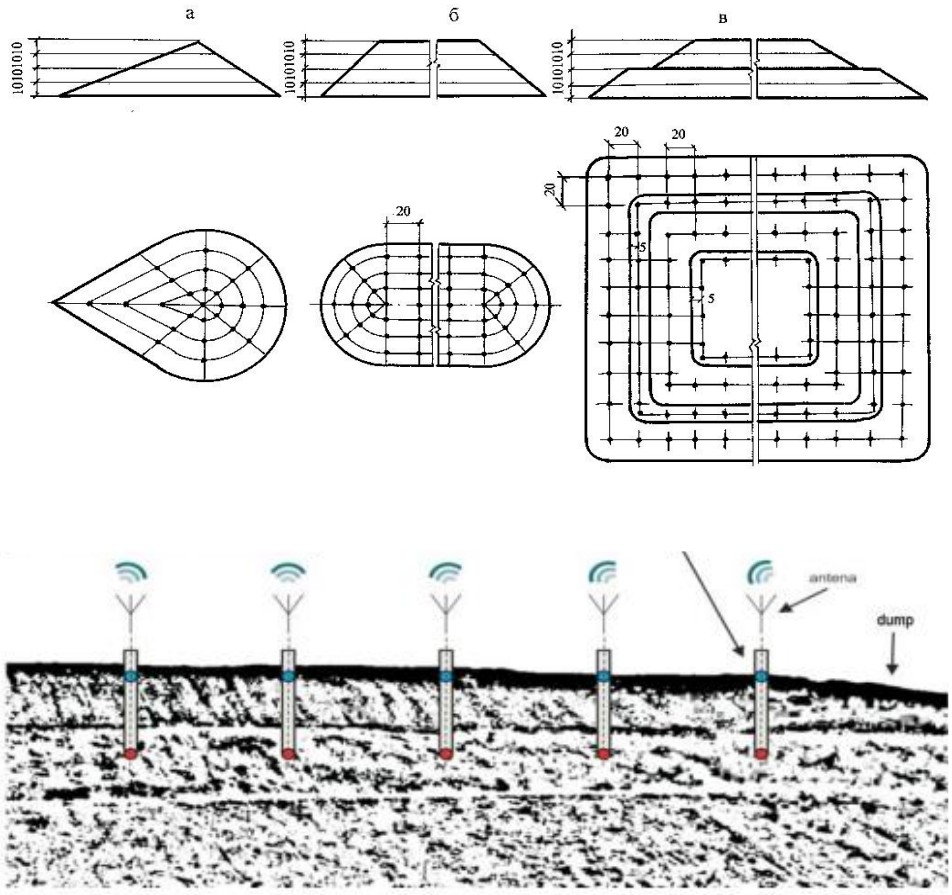


Figure. 2. Location scheme of information collection points from WSN sensors for monitoring coal tericon

The BME280 is capable of measuring pressure, temperature and humidity, so it will be important for monitoring the moisture saturation of air in the mine, the temperature inside the tericon and in the warehouse of finished products. If necessary, it can be replaced with other modules to perform individual tasks.

The SBM-20 radiation sensor will serve as a guarantee of miners' health during work and will warn about high level of radionuclides.

To use radio communication, it is advisable to take the SI4463 radio module.

The Arduino Nano V3 board with the ATmega328 microcontroller will enable the system to autonomously control the processes of data collection and transmission with a sufficient amount of power.

For positioning in space, unlike the Internet, it is necessary to use a GPS tracker, such as NEO-6M. Other components remain unchanged.

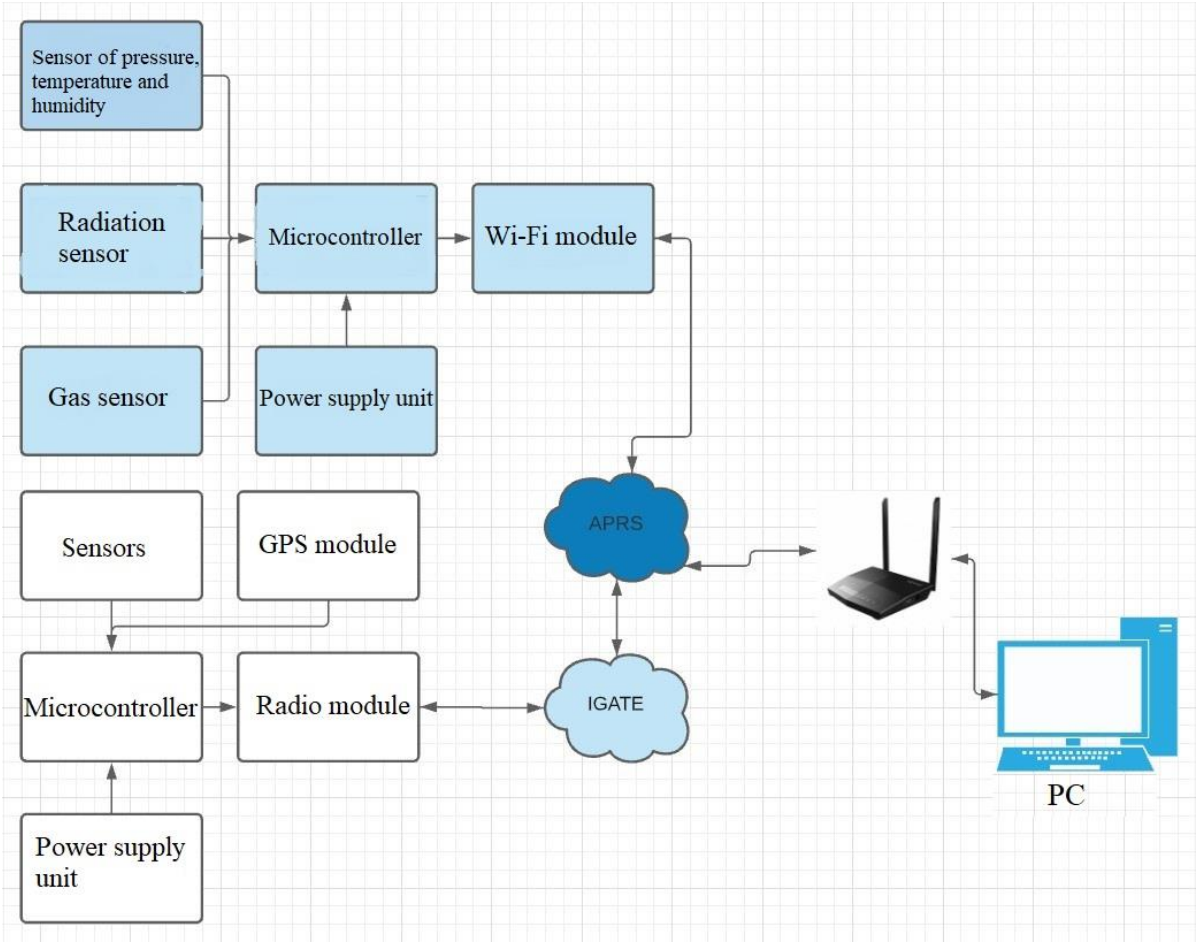


Figure. 3. Structural diagram of the hardware and software complex of the information system for monitoring environmental parameters

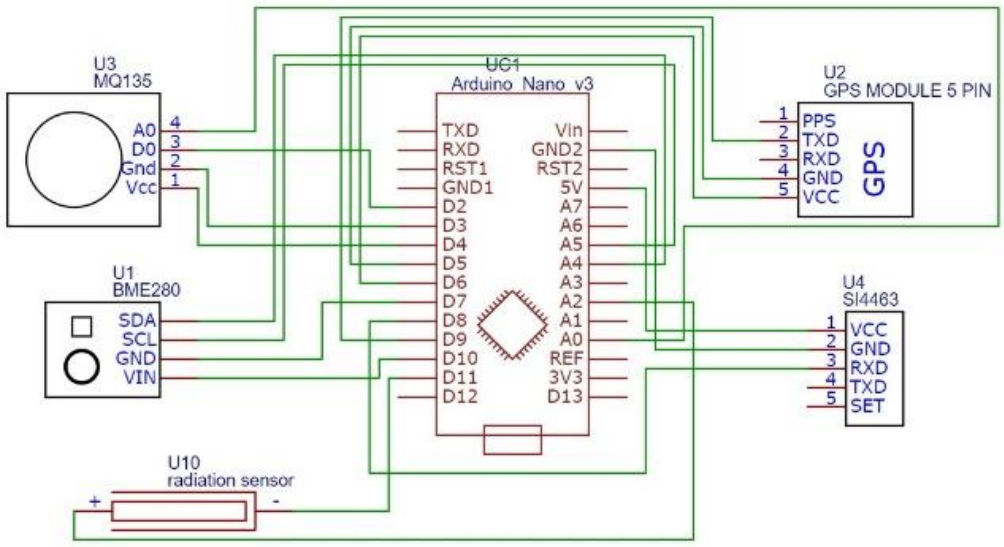


Figure. 4. Schematic diagram of the WSN and UAV radio module for monitoring coal mine tericon parameters.

Conclusion

The implementation of an information system for monitoring environmental parameters in the zone of influence of potentially dangerous objects in Donbas will effectively solve the problems of the coal mining industry regarding the processes of burning pits and dumps: the implementation of the Internet of Things (IoT) methodology will increase the effectiveness, speed and cost-effectiveness of monitoring.

Thus, after analyzing all the data available to us, we can come to the conclusion that there are no ideal ready-made options. Each monitoring method has advantages in its specific field of application and disadvantages in others. This fact prompts us to create our own methodology, which would incorporate all the positive features of previous methods to fulfill our goals.

Among the positive factors of the use of UAV, the following are distinguished:

- a low shooting height - from 10 to 200 meters to obtain ultra-high resolution and gas-thermal sensitivity (units and tenths of a centimeter) on the ground;

- pinpoint accuracy - the possibility of detailed shooting of small objects and small areas where it is completely unprofitable or technically impossible to do it in other ways, for example, in the conditions of urban development;

- mobility – no airfields or specially prepared airstrips are needed, UAVs are easily transported by cars (or carried by hand), there is no complex procedure for permits and coordination of flights; - high efficiency - the entire cycle, from going for the shooting to receiving the results, takes several hours;

- ecological cleanliness of flights - low-power gasoline or silent electric engines are used, almost zero environmental impact is ensured.

The negative factors of using ALS include:

- local scale of application – compared to remote sensing using a satellite, the camera equipment of which covers the entire country or part of it, the UAV can cover only one area in the same period of time.

- economic factor - on the other hand, to allocate UAV to each tericon is a completely losing idea from an economic point of view, if you add to the costs the wages of UAV operator.

The Internet of Things (IoT) is a concept that describes a network of objects - "things", which includes devices, software, sensors and other technologies for the purpose of connecting and exchanging data with other devices and systems using standard Internet communication protocols. The main difference from the "human Internet" is low power, because the devices do not need video or images, instead, to execute commands, they need binary codes and signals, which are easily transmitted by short waves of the radio communication channel. One of the possible options for solving the problem of burning tericons is the use of a system of sensors connected on the basis of IQRF.

IQRF is a platform for low-speed, low-power, reliable and easy-to-use wireless connectivity (RF - radio channel), e.g. for telemetry, industrial control and building automation. It can be used with any electronic equipment. We are able to use it when wireless information transmission is required, e.g. remote control, monitor, alarm, displaying remotely received data or connecting more devices to a wireless network. IQRF is a complete single-brand ecosystem that includes hardware, software, development support and services. The IQRF network can be easily connected to the Internet via a cloud server. IQRF is ideal for IoT implementation.

IQRF parameters:

1. RF bands: worldwide ISM 433 MHz, 868 MHz and 916 MHz;
2. Based on receiver modules with built-in operating system (OS);
3. Fully open functionality depends exclusively on the specific user of the program written in the C language;
4. Packet-oriented communication, max. 64 B per packet;
5. Range up to several hundred meters per jump, up to 240 jumps per package;

6. Very low power consumption: 380 nA in standby mode, 25 μA in reception;
7. Low data transfer speed: 19.2 kb/s. Previously: 1.2 kb/s, 57.6 kb/s and 86.2 kb/s.

At the same time, the biggest negative side of using IoT is the confidentiality issue. There is a possibility that your data may be misused.

Another no less negative side is the different IoT standards. For example IEEE & ISO/IEC. If devices from different manufacturers use different standards, interoperability will be more difficult, requiring additional gateways to translate from one norm to another.

Further researchit is planned to be carried out in the direction of the development of an integrated software and hardware complex for monitoring tericons and an algorithm for the primary processing of information from both UAVs and WSN.

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Автоматизація моніторингу радіаційного фону та викидів небезпечних газів з вугільних породних відвалів з використанням БПЛА та безпровідних сенсорних мереж в умовах ведення бойових дій

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Анотація. На сьогоднішній день актуальність питання розробки автоматизованих засобів моніторингу парникових газів на вугільних териконах в умовах протидії збройній агресії РФ отримують пріоритетне значення у зв'язку зі значною потенційною загрозою для навколишнього середовища та безпеки життєдіяльності населення, що проживає на прилеглих територіях. У випадку застосування ракетних та авіаційних засобів ураження по породним відвалам вугільних шахт відповідно відбувається зростання рівнів ризику ураження підрозділів та частин Збройних Сил, що знаходяться на цих територіях. Аналіз публікацій за напрямом автоматизації моніторингу викидів небезпечних газів з використанням засобів повітряного спостереження показує, що застосування БпЛА для цих завдань в умовах ведення бойових дій дозволяє знизити ризики для особового складу підрозділів РХБ захисту та оперативно-рятувальних підрозділів ДСНС. Стрімкий технологічний розвиток засобів автоматизації моніторингу виявив низку завдань для вирішення яких ефективним буде поєднання БпЛА та безпроводових мереж спостереження за викидами небезпечних газів. Це завдання може вирішуватись з міні та мікро БпЛА, стаціонарними постами спостереження та пересувними МЕСН мережами, яке на даний час залишається складною, системною, і до цих пір ефективно не вирішеним. В роботі представлено складові розробленої автоматизованої системи моніторингу викидів небезпечних газів з вугільних породних відвалів, обґрунтовано її склад, системе обробки інформації та передачі інформації в центри обробки даних.За результатами публікації запропоновано рекомендації щодо формування складу датчиків, типів міні та мікро БпЛА, застосування розробленого комплексу технічних та організаційно-тактичних заходів для здійснення моніторингу вугільних породних відвалів.

Ключові слова: система моніторингу, породні відвали, автоматизація, засоби повітряного спостереження, міні та мікро БпЛА, небезпечні гази.