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Air monitoring system based on IoT

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A number of researches shows the correlation between the COVID-19 coronavirus lethality and the air pollution. Therefore, the research and development of the air quality monitoring systems for domestic, industrial, and municipal use, as well as collecting and processing data for those systems are of great importance. The aim of this work is to develop a budget, intuitive, integrated Internet of Things (IoT) "Smart House" system. The IoT system for monitoring air quality and controling its parameters has been designed. The analysis of scientifical and technical information, design, hardware, and software development of IoT "Smart House" system and an appropriate web application has been performed to achieve this goal. Mathematical modeling, system programming, computer and microprocessor architecture, robotics, and the methods of network communication have been used. The integrated IoT system evaluates and analyzes the node for measuring the parameters of the environment in the room and the rules of fuzzy control according to experimental data, conducts a questionnaire to summarize the work. The main focus of the research has been on the system integration, the ability to connect a large number of sensors, air quality control, and effective control of the loading devices so that people can feel comfortable. The IoT system analyzes the indoor, as well as outdoor environmental data using a certain algorithm, and determines the node for measurement, using the minimum change and the minimum mean deviation. This algorithm allows us to stabilize the system management, to reduce the impact of erroneous or pseudo-erroneous data, etc. The functionality of the Smart House system ensures indoor comfort and safety, increases energy efficiency, and simplifies the management of various automated control systems in the household. In the following work, we are planning to improve the system by updating user-friendly interface, improving algorithms, expanding the functionality of the system, and performing in-depth study of the processes of measuring and controlling air quality parameters.

Keywords: *IOT, air monitoring, Smart House, control system.*

Система моніторингу якості повітря на базі IoT

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Ряд досліджень вказують на зв'язок летальності коронавірусу COVID-19 із забрудненістю повітря. В умовах пандемії багато людей перебувають на карантині та сидять у своїх домівках. Тож актуальними є дослідження та розробка систем моніторингу якості повітря для побутового, промислового та муніципального використання, а також роботи щодо збору та обробки даних цих систем. Тож метою даної роботи є розробка бюджетної інтуїтивно зрозумілої інтегрованої IoT системи «розумного будинку», яку можна було б застосувати для широкого спектру завдань з моніторингу якості повітря у приміщенні та керування його параметрами для підвищення його безпечності для життєдіяльності споживача. Розроблена інтегрована Internet of Things (IoT) система дозволяє інтегрування велику кількість датчиків, проводити моніторинг якості повітря та ефективно керувати виконуючими пристроями у приміщенні для поліпшення його стану. Ця система аналізує дані про навколишнє середовище в приміщенні та за його межами, використовуючи розроблений алгоритм, що дозволяє стабілізувати управління системою, зменшити вплив помилкових або псевдо помилкових даних та врахувати вподобання споживача. У майбутньому планується поліпшення системи за рахунок створення більш зручного інтерфейсу для користувача, покращення алгоритмів роботи та розширення функціональності системи та поглибленого дослідження процесів вимірювання та контролю параметрів якості повітря.

Ключові слова: *Інтернет речей, моніторинг якості повітря, «розумний будинок», система керування*

Система мониторинга качества воздуха на базе IoT

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Ряд исследований указывают на связь летальности коронавируса COVID-19 с загрязненностью воздуха. В условиях пандемии много людей находится на карантине и сидят в своих домах. Поэтому актуальными являются исследования и разработка систем мониторинга качества воздуха для бытового, промышленного и муниципального использования, а также работы по сбору и обработке данных этих систем. Поэтому целью данной работы является разработка бюджетной интуитивно понятной интегрированной IoT системы «умного дома», которую можно было бы применить для широкого спектра задач по мониторингу качества воздуха в помещении и управления его параметрами для повышения его безопасности для жизнедеятельности потребителя. Разработана интегрированная Internet of Things (IoT) система позволяет интегрировать большое количество датчиков, проводить мониторинг качества воздуха и эффективно управлять исполнительными устройствами в помещении для улучшения его состояния. Система анализирует данные об окружающей среде в помещении и за его пределами, используя разработанный алгоритм, позволяющий стабилизировать управления системой, уменьшить влияние ложных или псевдо ложных данных, а также учесть предпочтения потребителя. В будущем планируется развитие системы за счет создания более удобного пользовательского интерфейса, улучшение алгоритмов работы и расширения функциональности системы и углубленного исследования процессов измерения и контроля параметров качества воздуха.

Ключевые слова: *Интернет вещей, мониторинг качества воздуха, «умный дом», система управления*

The pandemic caused by COVID-19 presents new challenges for the humanity. A number of studies around the world (e.g. [1]) indicates the strong correlation between coronavirus lethality and air pollution. Higher mortality has been observed in the regions with poor air exchange and the high level of nitrogen dioxide in the air. It is a common belief that the air at the metropolis streets is polluted [2], but the global lockdown has led to the significant reduction of the environmental pollution [3]. But the situation is completely different in the dwellings where people have to stay for long periods of time due to the quarantine caused by the pandemic. Modern building materials, interior decoration, home appliances, furniture, etc. release a significant amount of toxic substances. Dust and mold often appear in poorly ventilated rooms, such as bathrooms and kitchens. The natural ventilation is often impaired by the pursuit of energy efficiency. According to some estimates, the air toxicity in a hermetically closed room can be ten times higher than outdoors. Air quality monitoring makes it possible to determine air quality, as well as to decide on the appropriate measures for its cleaning. For example, the recuperators, air cleaning, ventilation, dehumidication or humidification, and disinfection systems could be installed. Researches related to the monitoring of indoor and outdoor air and its impact on human's health have become very actual and vital [4-6]. Air quality monitoring systems for domestic, industrial and municipal use are being actively developed [7]. The air quality monitoring system should collect and process a lot of data that characterize air safety [8].

Being an accessible and intuitive, integrated Internet of Things (IoT) systems are one of the keys to solving this problem. Almost all systems and infrastructure of any buildings can be integrated into the network through the miniaturization of sensors, their availability and diversity. However, IoT-based systems require a well-built infrastructure and the usage of artificial intelligence for working in optimized and offline mode.

The functionality of the Smart House systems allows us to ensure the comfort and safety of occupants, to increase the building energy efficiency and simplify the management of various automated control systems that are part of our lives. Moreover, such systems can increase quality of life for the people with disabilities. Increasing the technological literacy of consumers and reducing the cost of such equipment due to the expansion of the digital industry lead to the popularization of such systems and their spread in residential and commercial real estate. However, misinterpretation of "Smart House" concept sometimes leads to the fears of its excessive intelligence among consumers. But in reality a "Smart House" is nothing more than an automation system that combines control and monitoring of all processes in apartments, houses, offices, cottages, etc.

The aim of this work is to develop the integrated "Smart House" IoT system, which could be used for a wide range of tasks for monitoring air quality and controling its parameters.

To achieve this goal a number of tasks are to be solved.

Formulation of the problem:

1. To analyze a scientifical and technical literature and information concerning similar systems.
2. To design IOT system.
3. To develop "Smart House" hardware and software, including a server for the interaction of individual subsystems.
4. To create a web application.

There are three main options for the "Smart House" automation systems:

- Centralized or decentralized;
- With an open or closed protocol;
- Wired or wireless.

Various combinations of these parameters are possible, such as, "Smart House" wired, decentralized with an open protocol or "Smart House" wireless, centralized with a closed protocol, for example. Therefore, the following architectures and options have been considered.

a) Centralized automation systems.

The centralized control system provides programming of one central element, i.e. the logical module, with many outputs. This element can often be a controller that uses a specially designed program for a particular object. It can control the actuators and other subsystems. It allows using multitasking scenarios and working with a wide variety of equipment. Centralized automation systems can be wired or wireless.

The advantages of centralized automation systems are:

- the single interface for the system management.
- the ability to create multitasking scripts.
- the ability to connect any equipment to the system;

The disadvantages of centralized systems are:

- vulnerability, the whole system stops working if the central module fails.
- low flexibility, i.e. equipment configuration changes are expensive and sometimes unprofitable. Usually it is much cheaper to completely redesign the system.

b) Decentralized automation systems.

The decentralized system controls each actuator by a separate microprocessor which has its own independent memory. This approach ensures high reliability of such systems. When one of devices is broken, other devices will continue to work and system remains operational. Smart houses built on the KNX protocol is an example of a decentralized system.

The advantages of decentralized automation systems are:

- *reliability*, which is guaranteed by the independence of the system devices;
- *prevalence.* The popularity of the KNX standard simplifies installing and servicing due to the significant number of certified specialists in our country;
- *design.* A great number of various electrical accessories and sensors ensures simplicity of designing and provides for wide range functionality.

The main feature of the decentralized system is a large amount of available equipment.

c) Open protocol automation systems.

KNX protocol is open, therefore, a huge number of smart house equipment manufacturers offer devices based on it. The KNX Association tests all the devices it produces. The KNX logo on the device guarantees the high quality of the product. Although the cost of such systems is higher than for the system based on the closed protocols. Strict compliance with the standards of the association leaves little place for the implementation of the creative ideas when designing new devices as well.

e) Closed protocol automation systems.

These systems are implemented on their own closed protocols. The development process is much easer and develooment costs are lower, because there is no need to pay for the product approval. The equipment based on a closed protocol can be manufactured only by a protocol owner, therefore, the consumer is completly dependent on the single manufacturer.

Thus, the modern world of home automation systems is developing rapidly and gaining the popularity becoming extremely wide and diverse.

The basic concept of the Internet of Things (IoT) consists in the integration of virtuality and reality, and the interconnection of all things, that is, all things in the world: "people", "things", "time", "places" or "objects" can be connected to the Internet. The European Telecommunications Standards Institute (ETSI) defines IoT as a three-tier hierarchy, each of which is inextricably linked to its functions. There are three layers (Fig. 1).

1. Sensor Layer: this layer consists of components that can receive, control and identify. It is mainly responsible for getting information, such as RFID (radio frequency identification), temperature and humidity sensors.
2. Network Layer: this layer consists of components that can communicate and transmit. The information is transmitted to the appropriate devices for the communication and exchange by wire or wireless means, such as TCP / IP, Wi-Fi and Bluetooth.
3. Application layer: this layer mainly consists of hardware devices that process information tangible or intangible to the user, respectively. In the first case, information is displayed on computer software interfaces, so that users are able to assess the current situation and react accordingly. In the second case, for example, if the temperature is too high, the air conditioner will be turned on and the temperature will be set to the level comfortable for a user.

IoT has evolved from the initial P2P to P2M and then to M2M, and although it is widely used IoT still faces many challenges. Currently, problems occur at all levels.

1. Sensor level. IoT is so extensible that you can connect many different devices, each of which processes data differently. Without an universal standard for receiving, processing, and formatting the data, the effectiveness of IoT can never be improved.
2. Network layer. Due to the limitations of wired transmission many customers do not want to use it, so most of IoT transmissions are wireless currently. However, wireless transmission faces a specific set of its own problems such as architecture, bandwidth, anti-interference, security and efficiency, which cannot be solved by a standardized method. A single standard will be the key to the success of IoT promotion in the future.

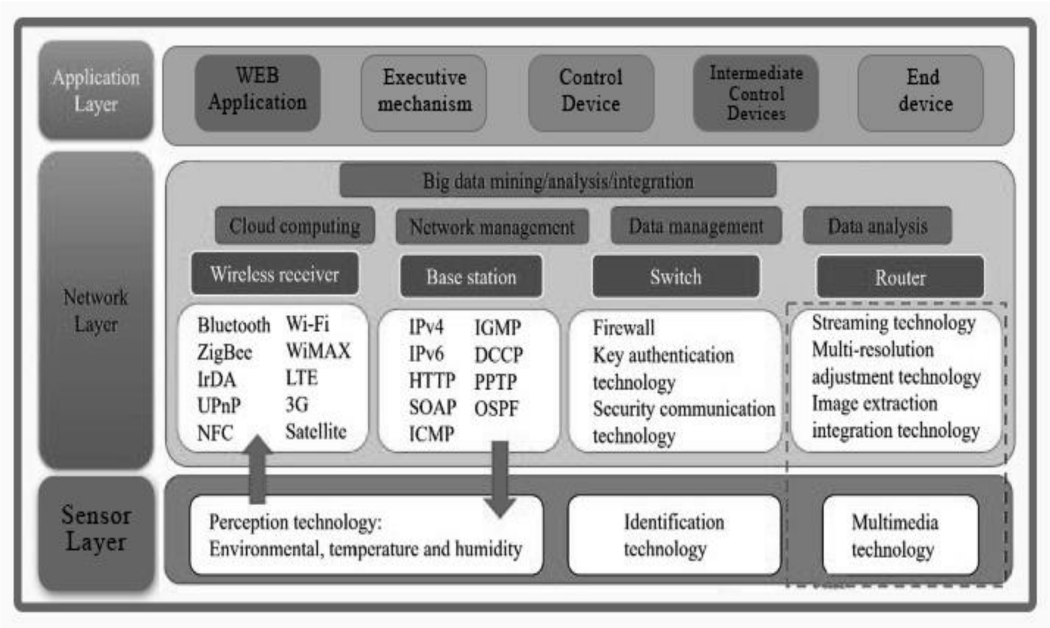


Fig. 1 - IoT system architecture.

3. Application level. IoT development brings a big data, such as data accuracy, application frequency and individual benefits. In times of an explosion of information that needs to be effectively processed, analyzed and forecasted, data will increase the value of data and prevent depreciation over time. With realisation of the self-planning, self-analysis, self-forecasting and self-repair for the IoT another milestone will be achieved. The Artificial Intelligence (AI) is not just a theoretical concept, but something that can be realized.

The architecture of the system is presented in four parts.

1. The first part is responsible for environment monitoring. It is part of an indoor monitoring equipment group. This equipment is represented by sensors, actuators and an Arduino analyzer [10]. The probe is responsible for data collection and enforcement.

2. The second part is the wireless transmission which provided by ZigBee transmission. Its main purpose is to transmit processed Arduino signals analyzed on a single-board computer.

3. The third part is responsible for analyzing and storing information. The analysis is based on the implementation of the indicators and standards mentioned in Part 2. The data are analyzed, processed, stored and displayed by the software.

4. The fourth part is a control qualitative management of the internal environment loading devices based on the received analysis. Loading devices, such as a buzzer, an electric fan, a humidifier, a conditioner and others are used for this purpose.

The automatic system control [11] can be based on the environmental situation or user preferences. The single-board computer sends a signal to the Arduino, which will regulate the temperature by controlling an air conditioner, fan and humidifier or turn on a fire alarm (in case of emergency) according to the signal received by ZigBee [12]. When the CO2 concentration is too high or exceeds the norm, a buzzer is activated by the node to alert the user which can take appropriate actions basing on the information provided. The complete system architecture is shown in Fig. 2.

The software architecture consists of three parts.

1. The final node. It is an indoor monitoring equipment that receives an analog signal for a certain period of time. The Arduino processes signals using a noise minimization algorithm to increase accuracy. After that, the processed data is transmitted through ZigBee to the coordinator. The data exchange process can be performed through each ZigBee node. The first node is the main control node. As soon as the single-board computer analyzes the received signal, the software node will determine a proper action scenario.

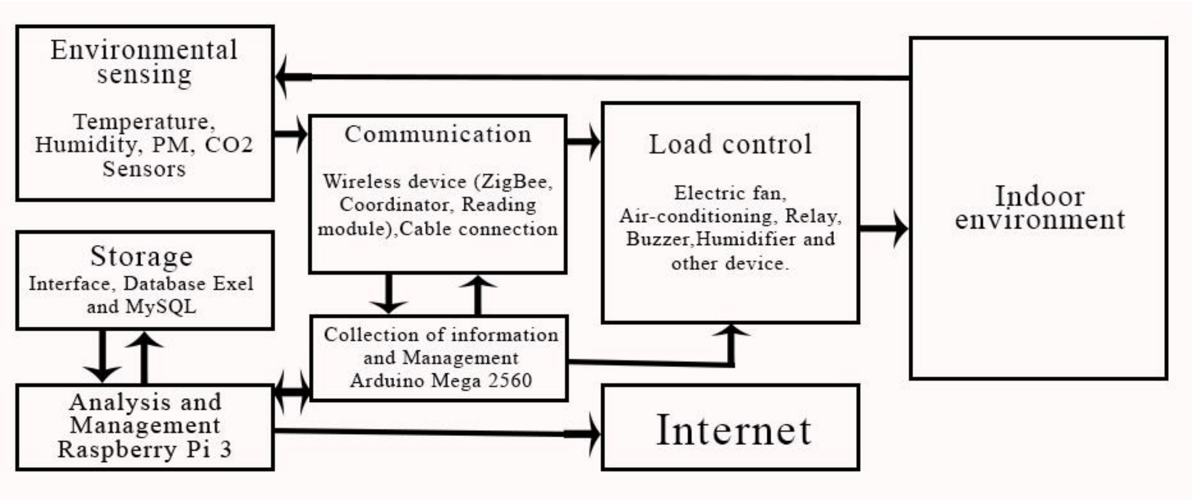


Figure 2. Scheme of data transmission architecture and control signals.

2. Single board computer. The data from each node is integrated for processing and analysis. The obtained results are stored in a database and form a knowledge base. If the result of the analysis of the internal environment is abnormal, then the correcting commands for an appropriate action are sent back to each node through the ZigBee coordinators. The usage of a single-board computer provides a significant advantage over other devices, because it offers sufficient system efficiency and high performance while processing large amounts of data.

3. The final computer. The end device processes received corrective commands and directly controls the loading devices.

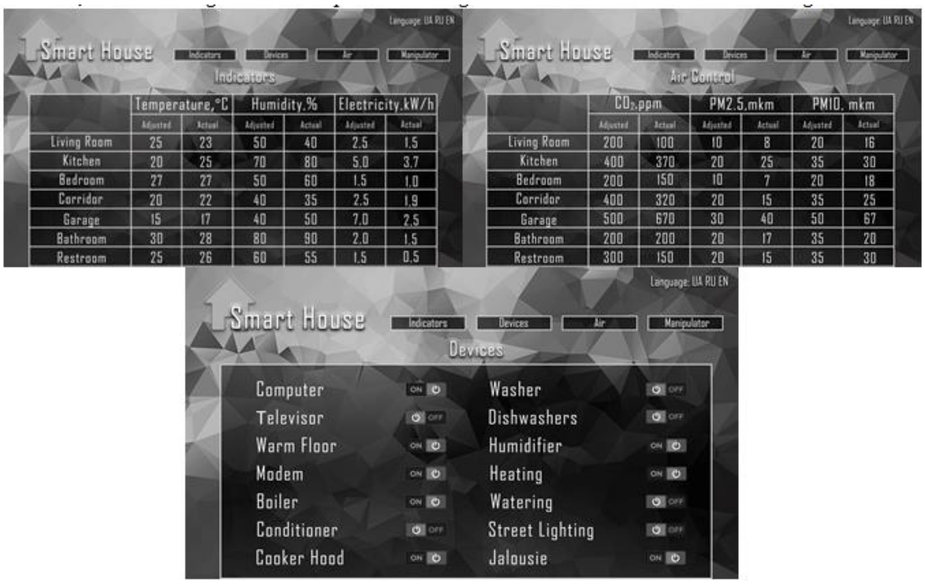
As the platform for the system the single-board computer RaspberryPi 3 and Arduino Mega 2560 have been chosen. This choice is based on the fact that a single-board computer performs calculations quickly, as well as has the ability to operate network systems and control other devices. Arduino is a very efficient tool that allows unexpensive implementation of any solutions for the device integration (sensors, servos, electric motors, etc.) and is widely used to solve problems of the automation and control. The connection between a single-board computer and Arduino complements each other and has great potential for IoT.

Integration is the main feature of our system. It is an ability to connect a large number of sensors and effective control of loading devices to ensure people's comfort and improve the quality of life.

HTML, CSS, and JavaScript are implemented to develop a human-machine monitoring interface. The human-machine monitoring interface receives and displays node data and provides system control. The interface is presented in Fig. 3. The obtained data is stored in the Microsoft Excel and MySQL database for further analysis and a single-board computer uses the relevant indicators and standards as a basis for evaluation.

Arduino Mega 2560 (AM 2560) software for collecting sensor information about temperature, humidity, wind speed, CO2 level, and particulate matter has been implemented with ArduinoStudio. The data from the AM 2560 is processed and analyzed on a single-board computer using software implemented with C/C ++. Communication between the computer and AM 2560 is realized as the ZigBee structure, where a single-board computer is the ZigBee server and AM 2560 is the ZigBee client. As soon as data from the sensor has been received, Arduino processes it and sends it to a single-board computer. The decision based on the recieved data is made and data is stored in the database. Afterwards the command to Arduino is sent, and Arduino controls the loading device.

The choice of the correct evaluation criteria is the most crucial; because if there is a huge discrepancy between the data measured at the node and the environmental conditions it can indicate that the node does not reflect the general situation correctly. In contrast, when the discrepancy is insignificant, the reliability of the node is much higher. The minimum variation and the minimum mean deviation can represent the stability and reliability of the node, respectively.



	Temperature,°C		Humidity,%		Electricity,kW/h	
	Adjusted	Actual	Adjusted	Actual	Adjusted	Actual
Living Room	25	23	50	40	2.5	1.5
Kitchen	20	25	70	80	5.0	3.7
Bedroom	27	27	50	60	1.5	1.0
Corridor	20	22	40	35	2.5	1.9
Garage	15	17	40	50	7.0	2.5
Bathroom	30	28	80	90	2.0	1.5
Restroom	25	26	60	55	1.5	0.5

	CO_2,ppm		PM2.5,mkm		PM10, mkm	
	Adjusted	Actual	Adjusted	Actual	Adjusted	Actual
Living Room	200	100	10	8	20	16
Kitchen	400	370	20	25	35	30
Bedroom	200	150	10	7	20	18
Corridor	400	320	20	15	35	25
Garage	500	670	30	40	50	67
Bathroom	200	200	20	17	35	20
Restroom	300	150	20	15	35	30

Figure 3. WEB interface.

It should be noted that the deviation of some parameters in the room might affect the values of parameters which are not obviously related. For example, when the relative humidity exceeds 70%, the sensors that are monitoring the concentration of solid particles will perceive the water particles as pollution as well [13]. That can be overcome by heating the air nearby the sensor or by intelligent processing of the sensor output.

The system that uses the IoT capabilities and intelligent algorithms for processing data from various devices in order to create and control favorable and secure environment for a user has been developed. The system integration is provided by the possibility of expanding the system easily and customizing each device to users preferrences due to the capabilities of the selected platform. The database for the data storage and its further statistical analysis has been provided. The environmental data stored in tables can be used for forecasting and preventing undesirable events. This system is fast enough for swift data processing and management, and shows a good efficiency. This is realized by using a single-board computer as the main device that controls the system. The user interacts with the system through a web page. It is possible to configure the system, have access to all information and perform certain actions to ensure comfort and safety.

As a result of performed work we have obtained:

- the intelligent system management algorithm,which takes user needs into account;
- the databases and tables for the data storage;
- the web page for the system management;
- the integrated IoT system that can be used for a wide range of environment monitoring and managing tasks.

The developed integrated Internet of Things (IoT) system evaluates and analyzes the node data for measuring the environmental parameters. It performes a fuzzy control according to experimental data and conducts a questionnaire to summarize the work. The main focus of research is on system integration, the ability to connect a large number of sensors, air quality control and effective control of loading devices to ensure people's safety and comfort, and improve the quality of life.

The system analyzes the indoor and outdoor environmental data using a certain algorithm and determines stability and reliability of the node measurement, using the minimum change and the minimum mean deviation.

To provide the control of CO2 and PM level in the environment the system are equipped with the corresponding sensors.

The system has been designed to facilitate monitoring and management of the performance of a particular room. It provides a comfortable environment for the user and increases safety by means of automatic control of critical situations.

In the following work, we are planning to improve the system by updating user-friendly interface, improving algorithms, expanding the functionality of the system, and performing in-depth study of the processes of measuring and controlling air quality parameters.

ЛІТЕРАТУРА

1. Y. Ogen, "Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality", *Science of The Total Environment*, vol. 726, p. 138605, 2020. Available: 10.1016/j.scitotenv.2020.138605 [Last accessed: 7.05.2020].
2. "Монитор качества воздуха в помещении", *M.habr.com*, 2017. [Online]. Available: https://m.habr.com/ru/post/322080/. [дата звернення: 11.05.2020].
3. S. Muhammad, X. Long and M. Salman, "COVID-19 pandemic and environmental pollution: A blessing in disguise?", *Science of The Total Environment*, vol. 728, p. 138820, 2020. Available: https://www.sciencedirect.com/science/article/pii/S0048969720323378. [Last accessed: 28.04. 2020].
4. C. Vornanen-Winqvist et al., "Exposure to indoor air contaminants in school buildings with and without reported indoor air quality problems", *Environment International*, vol. 141, p. 105781, 2020. Available: http://www.sciencedirect.com/science/article/pii/S0160412019338838. [Last accessed: 27.04.2020].
5. R. Chen, K. Ho, G. Hong and K. Chuang, "Houseplant, indoor air pollution, and cardiovascular effects among elderly subjects in Taipei, Taiwan", *Science of The Total Environment*, vol. 705, p. 135770, 2020. Available: http://www.sciencedirect.com/science/article/pii/S0048969719357651. [Last accessed: 25.04.2020].
6. J. Madureira, K. Slezakova, C. Costa, M. Pereira and J. Teixeira, "Assessment of indoor air exposure among newborns and their mothers: Levels and sources of PM10, PM2.5 and ultrafine particles at 65 home environments", *Environmental Pollution*, vol. 264, p. 114746, 2020. Available: http://www.sciencedirect.com/science/article/pii/S0269749120310551. [Last accessed:30.04.2020].
7. S. Kephalopoulos, S. Bopp, S. Costa, A. Cusinato, D. Lipsa and O. Geiss, "Indoor air monitoring: Sharing and accessing data via the Information Platform for chemical monitoring (IPCHEM)", *International Journal of Hygiene and Environmental Health*, vol. 227, p. 113515, 2020. Available: http://www.sciencedirect.com/science/article/pii/S1438463919310752. [Last accessed: 29.04.2020].
8. H. McDermott, "Air Monitoring for Toxic Exposures", 2004. Available: 10.1002/0471670588 [Last accessed:05.05.2020].
9. "2019 Insight Intelligent Technology Index", *itWeek*, 2020. [Online]. Available: https://www.itweek.ru/digitalization/article/detail.php?ID=210977. [Last accessed:18.05.2020].
10. "Arduino:Libraries/OneWire", *Wikihandbk*, 2020. [Online]. Available: http://wikihandbk.com/wiki/. [Last accessed:22.09.2019].
11. G. Mois, S. Folea and T. Sanislav, "Analysis of Three IoT-Based Wireless Sensors for Environmental Monitoring", *IEEE Transactions on Instrumentation and Measurement*, vol. 66, no. 8, pp. 2056-2064, 2017. Available: https://ieeexplore.ieee.org/abstract/document/7887698. [Last accessed:19.12.2019].
12. F. Montori, L. Bedogni and L. Bononi, "A Collaborative Internet of Things Architecture for Smart Cities and Environmental Monitoring", *IEEE Internet of Things Journal*, vol. 5, no. 2, pp. 592-605, 2018. Available: https://ieeexplore.ieee.org/abstract/document/7961139. [Last accessed:05.01.2020].
13. "Eco-City FAQ", *Eco-city.org.ua*, 2020. [Online]. Available: https://eco-city.org.ua/faq. [Last accessed:03.05.2020].

REFERENCES

1. Y. Ogen, "Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality", *Science of The Total Environment*, vol. 726, p. 138605, 2020. Available: 10.1016/j.scitotenv.2020.138605 [Accessed 7 May 2020].

2. "Indoor air quality monitor", *M.habr.com*, 2017. [Online]. Available: https://m.habr.com/ru/post/322080/. [Accessed: 11- May- 2020].
3. S. Muhammad, X. Long and M. Salman, "COVID-19 pandemic and environmental pollution: A blessing in disguise?", *Science of The Total Environment*, vol. 728, p. 138820, 2020. Available: https://www.sciencedirect.com/science/article/pii/S0048969720323378. [Last accessed: 28.04. 2020].
4. C. Vornanen-Winqvist et al., "Exposure to indoor air contaminants in school buildings with and without reported indoor air quality problems", *Environment International*, vol. 141, p. 105781, 2020. Available: http://www.sciencedirect.com/science/article/pii/S0160412019338838. [Last accessed: 27.04.2020].
5. R. Chen, K. Ho, G. Hong and K. Chuang, "Houseplant, indoor air pollution, and cardiovascular effects among elderly subjects in Taipei, Taiwan", *Science of The Total Environment*, vol. 705, p. 135770, 2020. Available: http://www.sciencedirect.com/science/article/pii/S0048969719357651. [Last accessed: 25.04.2020].
6. J. Madureira, K. Slezakova, C. Costa, M. Pereira and J. Teixeira, "Assessment of indoor air exposure among newborns and their mothers: Levels and sources of PM10, PM2.5 and ultrafine particles at 65 home environments", *Environmental Pollution*, vol. 264, p. 114746, 2020. Available: http://www.sciencedirect.com/science/article/pii/S0269749120310551. [Last accessed:30.04.2020].
7. S. Kephalopoulos, S. Bopp, S. Costa, A. Cusinato, D. Lipsa and O. Geiss, "Indoor air monitoring: Sharing and accessing data via the Information Platform for chemical monitoring (IPCHEM)", *International Journal of Hygiene and Environmental Health*, vol. 227, p. 113515, 2020. Available: http://www.sciencedirect.com/science/article/pii/S1438463919310752. [Last accessed: 29.04.2020].
8. H. McDermott, "Air Monitoring for Toxic Exposures", 2004. Available: 10.1002/0471670588 [Last accessed:05.05.2020].
9. "2019 Insight Intelligent Technology Index", *itWeek*, 2020. [Online]. Available: https://www.itweek.ru/digitalization/article/detail.php?ID=210977. [Last accessed:18.05.2020].
10. "Arduino:Libraries/OneWire", *Wikihandbk*, 2020. [Online]. Available: http://wikihandbk.com/wiki/. [Last accessed:22.09.2019].
11. G. Mois, S. Folea and T. Sanislav, "Analysis of Three IoT-Based Wireless Sensors for Environmental Monitoring", *IEEE Transactions on Instrumentation and Measurement*, vol. 66, no. 8, pp. 2056-2064, 2017. Available: https://ieeexplore.ieee.org/abstract/document/7887698. [Last accessed:19.12.2019].
12. F. Montori, L. Bedogni and L. Bononi, "A Collaborative Internet of Things Architecture for Smart Cities and Environmental Monitoring", *IEEE Internet of Things Journal*, vol. 5, no. 2, pp. 592-605, 2018. Available: https://ieeexplore.ieee.org/abstract/document/7961139. [Last accessed:05.01.2020].
13. "Eco-City FAQ", *Eco-city.org.ua*, 2020. [Online]. Available: https://eco-city.org.ua/faq. [Last accessed:03.05.2020].

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