An IoT system based on open APIs and geolocation for the prevention of human health disorders

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Abstract. The article presents a study devoted to improving the developed Internet of Things system based on open APIs and geolocation, which is aimed at analyzing data about the state of the environment using an expert approach and data visualization for possible prevention of human health disorders. Based on the developed Internet of Things system, open APIs, geolocation using intelligent gadgets, and the Meteorological Geographic Information System, the study generates a message about the danger to human health associated with meteorological factors. Accordingly, a person is informed promptly about potential risks and threats, particularly about the presence of pollen in the air, indicating the level of its concentration in the air, and about problems with air quality. What is the "anthropo-geo-sensory-digital" prerequisite for making effective real-time decisions to prevent human health disorders?
New features were added to the developed system to analyze data about potential risks and threats that could lead to human health disorders, in particular, about the presence of temperature problems, under the condition that this indicator goes beyond the normative and optimal zone; the presence of relative humidity problems, under the condition that this indicator go beyond the normative and optimal zone; the presence of wind speed problems, if the air wind speed exceeds the permissible standards. Effective decision-making based on providing timely information about potential risks and threats to human health, in addition to preventive, has significant methodological and technological potential that can be used to improve the effectiveness of health care, both in extreme conditions and in conditions of sustainable existence. The system developed and improved by us can also be considered as one of the ways of introducing innovations in health care, the IT field, the educational process in institutions of higher education and conducting further research in this field, in particular, in the direction of data processing in health care systems based on machine learning.[1]

Keywords: IoT, Open API, Smart-Gadget, Smartphone, Meteorological Geographic Information System, Cloud Services, Cloud Computing, eHealth, human health, Healthcare, human health disorders, prevention, Air quality index, Air pollution, pollen, meteorological factors

[1]This article is an extended version of a conference talk presented at the Workshop on Cloud-based Smart Technologies for Open Education (CSTOE 2022) [10].

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1. Introduction

At this stage of the development of Internet of Things (IoT) technologies, more and more attention is paid to developing healthcare applications in IoT systems, as they provide an opportunity to remotely monitor human health in real-time [10].

The demand for professional use of IoT systems for real-time health monitoring in relation to environmental conditions, including environmental risks, is present in many fields of activity, science and education [10, 11, 13, 14, 23, 29]. Important is the analysis of big data in the field of health care, obtained with the help of the IoT, which today is used to detect and prevent the development of various diseases. This direction has gained particular importance over the past three years in connection with the COVID-19 pandemic. One of the possibilities of integrating these technologies is their use to collect sensor data in real-time by monitoring individuals, for example, with the help of Smartwatches and other gadgets.

Relationships between the specified technologies and the healthcare field are decisive in this aspect. This is being realized thanks to the proliferation of medical and other wearable devices, which have rapidly gained significant popularity over the past few years. Numerous studies in this field show that such systems are effective and that their use does not cause significant discomfort to patients. Another aspect that researchers are paying attention to is the seamless operation of the IoT and the protection of patient data. Also, in modern conditions, the development of IoT systems is carried out by combining the technologies of the IoT, artificial intelligence (AI), cloud computing, etc.[10].

In our opinion, the most important priority from the point of view of preserving health is the prevention of human health disorders. Monitoring the state of weather conditions to prevent risks related to human health is currently a relevant direction in the implementation of preventive measures. It is also important that a person receives timely information about possible health threats, especially during outdoor sports.

There is a need to minimize risks to human life and health and optimize the training process. This is carried out by taking into account physiological indicators and environmental data in the work of a coach, instructor, and physical culture teacher by using IoT systems for monitoring the state of health in real-time [10].

There is also a need to use these systems in rehabilitation to implement differentiated and individualized rehabilitation. These applications are particularly important for clinical medicine, including remote diagnostics and treatment, defining new opportunities for the objectification and technologization of medical practices, which is especially important during the COVID-19 pandemic [10].

Using these systems in ecology opens up new perspectives for considering the environment systemically, holistically, and technologically oriented consideration of the environment related to human activity. This gives ecology an anthropological and humanistic orientation and determines the possibilities of developing digital anthropo-socio-ecological technologies [10].

The concept of IoT, which allows “smart objects” to “communicate” with each other or the user [9, 28], is increasingly more popular. Thanks to IoT, we can get more information more easily than ever and manage objects much more efficiently [27]. IoT can be applied in many fields, including measurement, traffic control, smart homes, etc. [11, 17]. Sensors, smartphones, fitness bracelets, household appliances, counters and similar devices can be used as such objects.

Remote monitoring of human health based on the concept of IoT is popular today and is actively researched [4, 7, 10, 12, 22, 30]. Such monitoring is implemented both based on personal medical devices and special gadgets that provide such a function. As noted by researchers S. Chidambaranathan and R. Geetha [5], personal medical devices are a component of Smart Health Systems (SHS), reducing patient treatment costs. However, in remote monitoring of a person's condition, problems with the security of the data exchange network are possible [5]. Authors S. Chidambaranathan and R. Geetha propose an IPFS (InterPlanetary File System) and blockchain-based approach to address these cyber-attack challenges.

It is also essential to develop and implement such IoT systems that would expand the possibilities of air monitoring for the presence of allergens in the environment and, accordingly, present data on their concentration level in representative and user-friendly formats. In this regard, it is essential to monitor allergens of plant origin, which are the pollen of some plants [10].

In addition, monitoring of weather conditions and other data on the state of the environment may also be provided to prevent human health disorders [10, 13].

In addition, monitoring weather conditions and other data on the state of the environment may also be provided to prevent human health disorders. At the same time, it is essential to study indicators of the state of the environment both indoors [13, 25] and outdoors [1, 10]. The results of the conducted research on the use of the IoT system with peripheral devices on the premises of the educational institution are effective in ensuring sanitary and hygienic standards on the premises of the educational institution and, as a result, in the prevention of human health disorders.

The relevance of this study lies in the need to integrate the above technologies to prevent human health disorders. Currently, information systems based on IoT, fog computing, cloud computing, open APIs, geolocation data, etc., are being actively implemented in the healthcare industry and other industries. However, the problem of using systems that analyze geolocation data and meteorological data to detect threats to human health and prevent human health disorders in a timely manner remains unsolved.

Thus, the *purpose* of the study is to improve the developed IoT system based on open APIs and geolocation for analyzing data on the state of the environment using an expert approach and data visualization to prevent possible human health disorders.

2. Related Work

To prevent human health disorders, we investigated possible threats, particularly meteorological data and other data on the state of the external environment. In this area of research, scientists studied a combination of IoT, artificial intelligence, and cloud service technologies for real-time observations.

Previously, we analyzed the works of scientists for the five years from 2018 to 2022 from the point of view of their joint use of the terms "Internet of Things" and "human health" (Fig. 1).

According to Figure 1, scientists have explored the possibilities of using IoT technologies to preserve human health in telemedicine, disease diagnosis, sports fitness management, smart cities, etc. For this purpose, they used sensor monitoring, biometric monitoring, cloud computing,

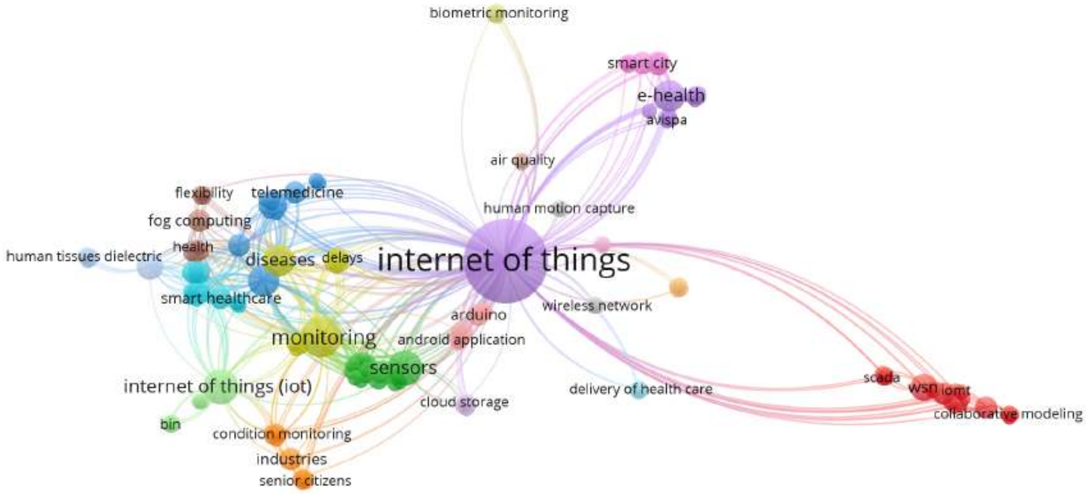

Figure 1: Map of the subject categories of scientists' research for five years from 2018 to 2022 according to the joint use of the terms "Internet of Things" and "human health" [3].

fog computing, Arduino hardware, Android applications and others.

The relationship between the mentioned technologies and the healthcare field is decisive in this aspect. This has become possible thanks to the proliferation of medical and other portable devices, rapidly gaining significant popularity over the past few years. Also critical is the analysis of big data in the healthcare field, obtained with the help of the Internet of Things, which is used today to detect and prevent the development of various diseases.

This direction has gained particular importance over the past three years in connection with the COVID-19 pandemic. One of the IoT's capabilities is collecting real-time sensor data by monitoring individuals, such as through smart watches and other gadgets.

In further work, we investigated whether scientists conducted research in which the "Internet of Things" and "human health" were jointly studied (Figure 2) from January 2022 to January 2024.

Comparing the obtained results, we can observe changes in the research vector regarding the combination of the "Internet of Things" and "human health" spheres, which took place from January 2022 to January 2024 inclusive. From the point of view of the use of technologies, these studies emphasize artificial intelligence, in particular, machine learning and deep learning, as well as real-time research. From the point of view of the impact on human health, researchers studied the environment, particularly temperature fluctuations, and the consequences of COVID-19.

Various aspects of the presented topic are studied by many foreign and domestic researchers, in particular: the use of machine learning, big data and IoT from the point of view of medical informatics (Tawhid M. A., Teotia T., Elmiligi H. etc.) [30]; application of IoT technologies and artificial intelligence in health care during the COVID-19 pandemic (Chatterjee P., Tesis A., Cymberknop L. J., Armentano R. L., etc.) [4, 30]; use of smart devices with IoT support in

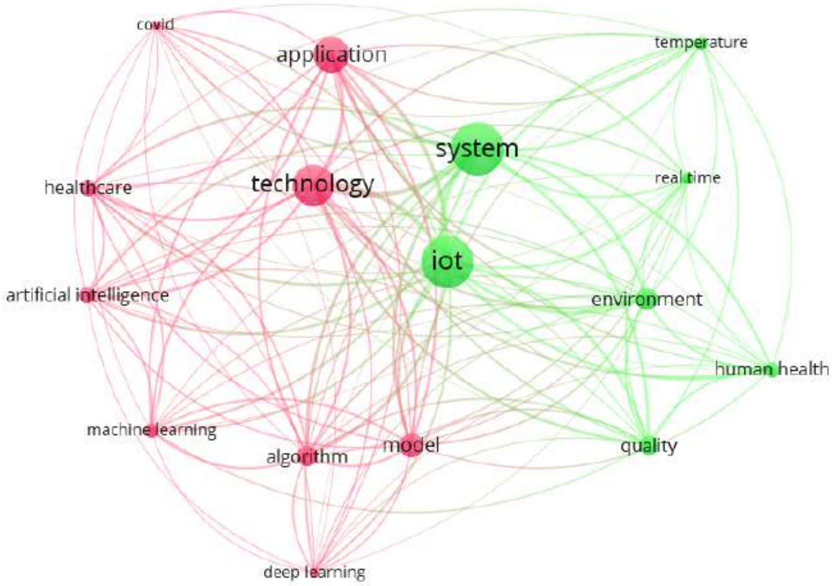

Figure 2: Map of the subject categories of scientists' research from January 2022 to January 2024, inclusive, based on the joint use of the terms "Internet of Things" and "'human health" [3].

healthcare (Mitchell K., Graham C., Chatterjee P., Tesis A., Cymberknop L. J., Armentano R. L., etc.) [4, 7, 10, 12, 22]; analysis of security threats, data corruption in the network and information security issues in health care related to IoT devices (Tawhid M. A., Teotia T., Elmiligi H., Korenivska O. L., Nikitchuk T. M., Vakaliuk T. A., Benedytskyi V. B., Andreiev O. V., Klochko O. V., Fedorets V. M. etc.) [10, 13, 30]; the issues of real-time data monitoring based on IoT, notifications software with geolocation, data analysis were investigated by Konduru P., Naga Surya S., Korenivska O. L., Nikitchuk T. M., Vakaliuk T. A., Benedytskyi V. B., Andreiev O. V., Klochko O. V., Fedorets V. M. and others [10, 12, 13].

The problems of increased anthropogenic influence (urbanization, industrialization) on the environment are increasing yearly. Air pollution leads to a deterioration of air quality and, in turn, increased threats to human health. To investigate these problems, Malla S. , Sahu P. K., Patnaik S., Biswal A. K., and Nayak M. developed an intelligent air pollution monitoring system that detects pollutants in the air, an infrastructure of IoT-based anti-smog towers that create a virtual greenhouse effect to mitigate the harmful effects on human health [17].

The issue of using machine learning, big data and IoT from the point of view of medical informatics was considered by Tawhid M. A., Teotia T., and Elmiligi H. Researchers also focus on the issues of preserving the confidentiality of medical data [30].

The use of IoT technologies and artificial intelligence in health care during the COVID-19 pandemic was investigated by Chatterjee P., Tesis A., Cymberknop L. J., Armentano R. L. [4]. The researchers reviewed the main aspects of eHealth services during COVID-19 and modern tools and solutions. In particular, they investigated the possibilities of using mobile applications to conduct virtual consultations.

Mitchell K. [22] also reviewed the possibilities of online patient engagement for treating

COVID-19 using IoT-enabled smart devices, healthcare body sensor networks, and online patient engagement for preventing, screening and treating COVID-19. He analyzed the data, determining the curve of the infection of COVID-19.

A feature of the research Liu J., Alo R. A., Bautista Y. J. P., Yedjou C. G. and Theran C. [16] uses geodata to monitor social and structural determinants of human health, especially during the COVID-19 pandemic, to find strategies to improve health care. The authors proposed a geospatial and ML-based approach (GMLTrace) for finding indicators of differences in the health status of patients and analyzing them, taking into account various determinants, for example, the elderly age of patients, racial and ethnic affiliation of patients, etc. [16].

Also, the use of smart devices with IoT support in the field of healthcare from the point of view of information security of healthcare organizations was investigated by Graham C. [7]. The study considered approaches to identify any new patterns and external threats associated with using IoT devices, both technical and behavioural. One of the important aspects of the research is new questions about not knowing how IoT devices work, the consequences of trusting IoT providers, and ways to reduce these risks.

Analysis of security threats, data corruption in the network and information security issues in health care related to IoT devices were investigated by such authors as Tawhid M. A., Teotia T., Elmiligi H. [30].

The issue of real-time data monitoring based on IoT, geolocation notification system, and data analysis was investigated by Konduru P. and Naga Surya S. [22]. They proposed a remote pulse monitoring system. Their proposed engineering solution involves collecting information from the sensor through a microcontroller and transferring it to databases, where it is further processed for consideration. The authors note that in this way, medical workers can track changes in the patient's health indicators.

Researchers Korenivska O. L., Nikitchuk T. M., Vakaliuk T. A., Benedytskyi V. B., and Andreiev O. V. developed a device that registers heart rate and saturation; the study provides that this data is transferred to a database on the edge server for further storage and processing [13]. Such a hardware complex based on IoT technology provides opportunities for monitoring the state of the cardiovascular system of students [13].

Kunal, Prakash A., Avasthi S., Agarwal K. and Hussain M. reveal the technological potential of AIoT (Artificial Intelligence of Things), which can be applied for remote monitoring of the body's vital activity indicators integratively using machine learning [15]. Vital indicators are monitored, among which data on heart function, oxygenation and blood coagulation system, and body temperature are significant[15]. The role of AIoT in the early detection of life-threatening diseases is revealed[15].

Researchers Pavitharani G. P., Joy R. T. and Rajendran R. K. studied the integrated impact of Artificial Intelligence and the Internet of Things in combination with applications from IoT-connected devices [24]. An important direction of these studies is the use of remote observations of patients and the development of individual treatment programs [24]. The application of this system is also aimed at equal access to medical services and the development of well-being [24].

Despite the significant interest of researchers in the issue of using human health monitoring systems that are implemented based on IoT technology, cloud computing, fog computing, open APIs, determining the location of a person based on geolocation data, the issue of developing and using applications based on open APIs with the use of Smart-gadgets and Meteorological

Geographic Information System (GIS, Geoinformation System (GIS); Meteorological Geoinformation System (MGIS)) for the preservation of human health and the prevention of possible human health disorders remain relevant and require solving problems that relate to various aspects of the tasks.

3. Selection of methods and diagnostics

In the process of work, research methods were used: analysis, synthesis, method of system analysis, methods of communication theory (development of a system that supports IoT technologies), modelling using the unified modelling language UML (in particular, to build a UML diagram of precedents), mathematical modelling, computer modelling (monitoring and data analysis) [10].

In the process of solving the tasks, the system analysis method was used to develop a system that supports the technologies of the IoT (AI, Cloud Computing, Open API, wireless access) [10].

Cloud computing, Open API, and wireless access methods were used to solve the tasks [10].

A smartphone with wireless technologies was proposed to combine devices based on open APIs using intelligent gadgets and a meteorological geographic information system. It has been used to track and analyze data related to human health, anywhere and anytime, interfacing with meteorological data to provide operational data (warnings) in real time about the likely presence of threats to human health [10] to prevent human health disorders.

The study considered two main groups of environmental factors as elements of the environmental system that influence the human body [10, 32]:

1. abiotic (temperature, humidity, solar radiation, atmospheric pressure, chemical air pollution, etc.);
2. biotic (pollen).

For the purpose of data analysis, sensor data and indicators about the state of human health, as well as the state of the surrounding environment, were used [10]:

- TotalDistance – total distance covered;
- TotalSteps – total number of steps;
- LastThousandSteps – the number of steps taken in the last 1000 m;
- AverageHeartRate – average heart rate;
- Temperature – air temperature now (2 m elevation corrected);
- WindSpeed – wind speed now (10 m);
- Pressure – pressure (mean sea level);
- RelativeHumidity – relative humidity (2 m);
- Rainspot – rain spot area;
- PollenBirch – pollen birch;
- PollenGrass – pollen grass;
- PollenOlive – pollen olive;

- AirQualityIndex – air quality index.

Meteorological geographic information system Meteoblue [19, 20] was used to quantify environmental factors (European Common Air Quality Index (CAQI), Particles, Gases, Pollen, Temperature, Precipitation, Wind speed and others) using open APIs (Figure 3, Figure 4) [10].

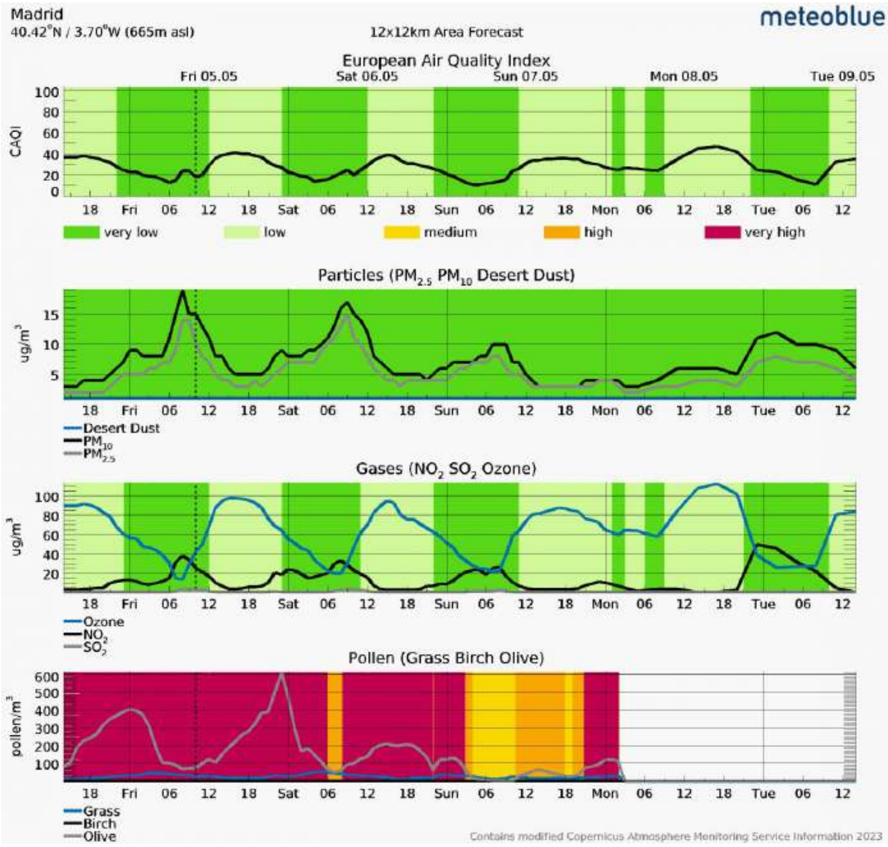

Figure 3: MGIS Meteoblue (European Common Air Quality Index (CAQI), Particles, Gases, Pollen) [19].

To determine the limits of temperature, humidity, wind speed and other indicators, the following methods were used: monitoring the state of the environment; determination of geolocation; comparison of the obtained values of the indicators with the determined ranges of their values; measurement of total distance covered, the total number of steps, average heart rate; system testing based on Historical Weather Data on the state of environmental pollution and weather conditions of Basel city; analysis, synthesis, modelling and other methods.

The Visual Studio Code development environment, The Open Source Python App Development Framework Kivy, and the Python programming language were used to develop new IoT system functionalities. The OpenStreetMap Carto (OSM Carto) visualization style was used to visualize the trajectory of human movement and demonstrate the levels of air pollution on a measurable scale [2].

Figure 5 shows the program code for calculating the distance between two points of geographic

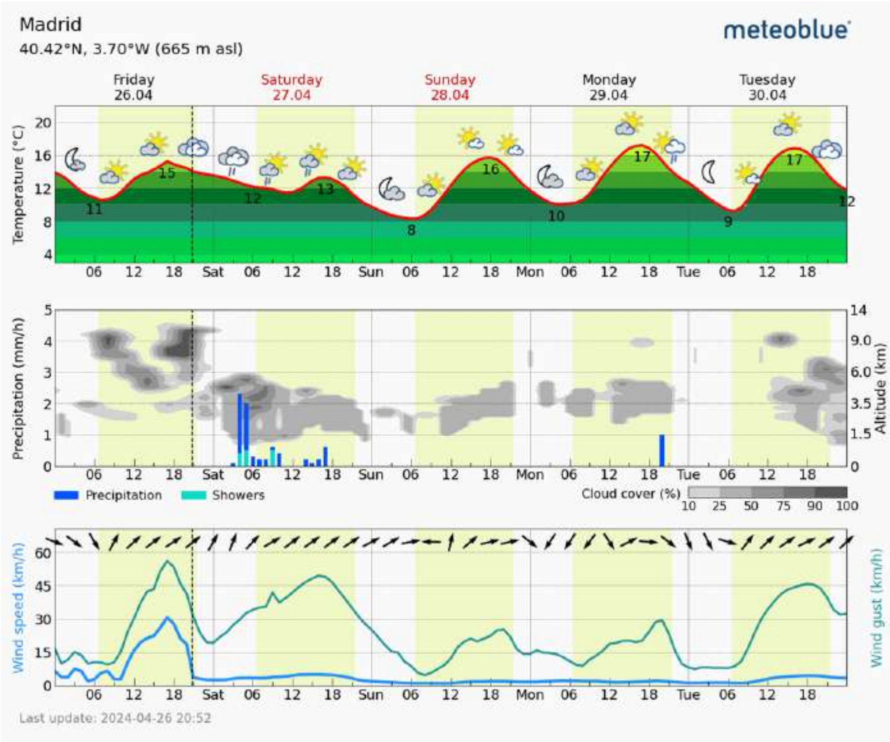

Figure 4: MGIS Meteoblue (Temperature, Precipitation, Wind speed) [20].

location in Python.

```
def distanceBTP(latitude1, longitude1, latitude2, longitude2):
    R = 6378.137 * 1000  # meters
    f1 = latitude1 * math.pi / 180
    f2 = latitude2 * math.pi / 180
    delf = (latitude2 - latitude1) * math.pi / 180
    dell = (longitude2 - longitude1) * math.pi / 180
    a = math.sin(delf / 2) * math.sin(delf / 2) + math.cos(f1) * math.cos(f2) * math.sin(dell / 2) * math.sin(dell / 2)
    c = 2 * math.atan2(math.sqrt(a), math.sqrt(1 - a))
    d = R * c  # in metres
    return d
```

Figure 5: Calculating the distance between two points of geographic location) [10].

4. Designing an IoT system based on open APIs and geolocation

Following the purpose of the study, the task was set to improve the developed "anthropo-digital" system for the prevention of human health disorders using IoT based on open APIs for monitoring and analyzing data related to human health, taking into account geolocation. For this purpose, it was planned to use Smart gadgets (fitness bracelets and smartphones) and a weather and geoinformation system [10].

The software application based on open API provides [10]:

1. collection and analysis of sensor data using Smart gadgets;
2. real-time data processing – analysis of environmental factors in order to identify possible threats to human health;
3. generation of a warning message to the user's mobile phone.

This system implements a warning about the threat of a person being in an environment with polluted air. Such notification is necessary to prevent the development of various diseases and to determine the influence of environmental factors on the working capacity and life expectancy of a person [8, 10].

The updated system works based on a UML case diagram to implement a wireless IoT system modelling process based on open APIs for location-aware human health data monitoring and analysis (Figure 6) [10]. The UML diagram of the precedents of the IoT system at the conceptual level represents the diagram of connections between the Actor and the precedents that characterize the capabilities of the IoT system (Figure 6) [10]:

- Relative indication of heart rate, number of steps and distance covered.
- Obtaining data on the state of the external environment.
- Monitoring of geolocation sensor data.
- Data processing and analysis of the state of the external environment based on geolocation data to identify possible threats to human health.
- Receiving warning signals about threats to human health.
- Receiving a notification about taking actions aimed at preserving health.
- Receiving a map of the route travelled with AQI indicators.

Thus, the IoT system's proposed architecture is a network model (Figure 7). It is assumed that the following are integrated in this model [10]:

1. Smart gadget (fitness tracker/smart watch). We used the Apple Watch 4 fitness tracker as an intelligent gadget;
2. Smartphone;
3. Scale-independent integrated meteorological geoinformation system;
4. Cloud services host software applications for monitoring and data analysis.

5. Results and Discussion

To develop an IoT system based on open APIs and geolocation for data analysis to prevent possible human health disorders, the relative indication of the pulse, the number of steps and the distance travelled, air pollution data, the presence of pollen in the air, and other meteorological data was monitored.

Data monitoring can be done anywhere and anytime by connecting to a person's fitness tracker and smartphone, as long as they are connected to a communication channel (Wi-Fi

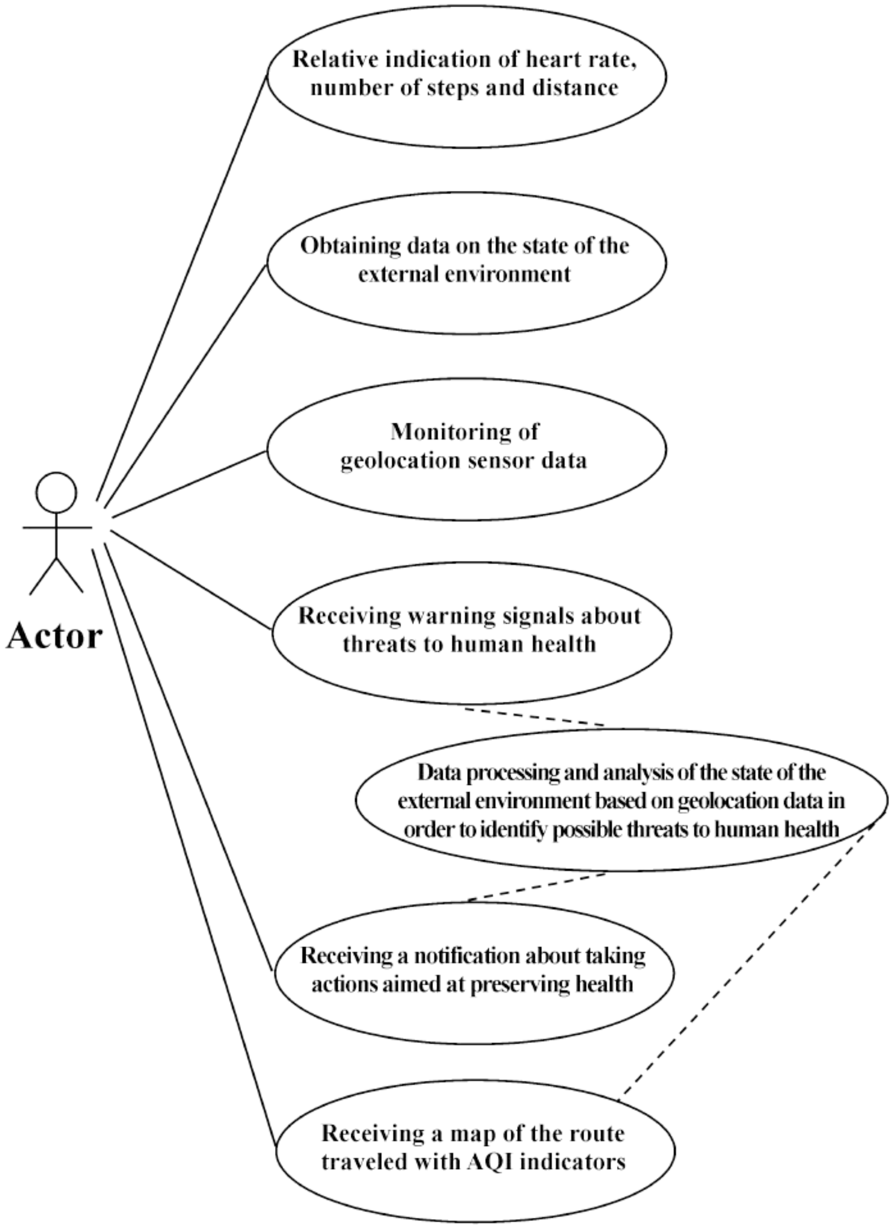

Figure 6: UML diagram of precedents, which reflects the relationship between the Actor and precedents in the IoT system [10].

network, mobile network, etc.). A software application based on open APIs was developed for data monitoring and analysis [10]. With the help of the application, you can perform a relative indication of heart rate, the number of steps, and distance travelled, as well as monitor and analyze data on air pollution, the presence of pollen in the air and other meteorological data. In addition to analyzing data on air pollution and the presence of pollen, we have added the possibility of analyzing relative air humidity, temperature and wind speed. As mentioned above,

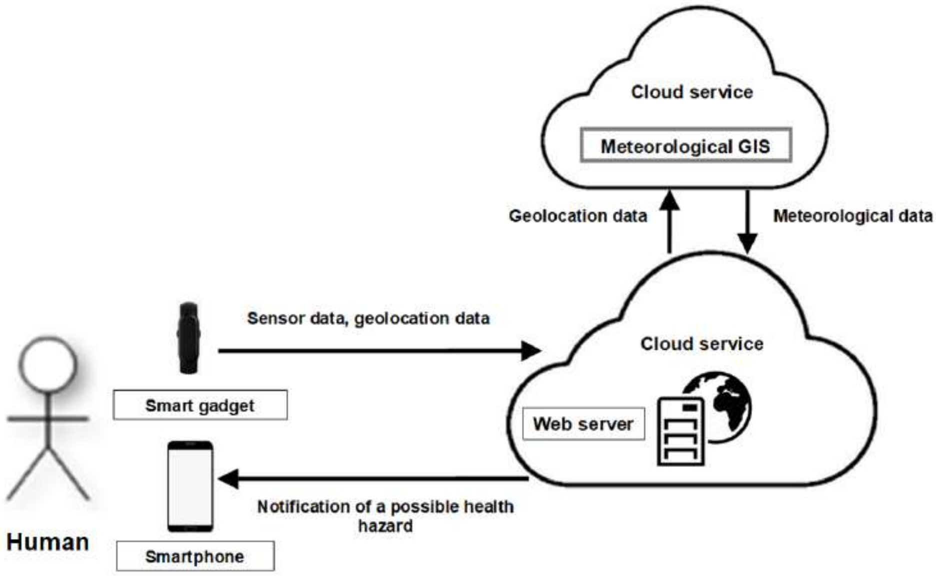

Figure 7: Architecture of a wireless IoT system based on open APIs and geolocation [10].

this is done to prevent possible human health disorders in real time promptly.

The quantitative assessment of environmental factors is carried out automatically online, taking into account human geolocation data and data on the state of the surrounding environment, which can be obtained using open APIs of the geoinformation system (Figure 3, Figure 4) [10]. Since it is not possible to reproduce the experiment in the conditions of the previous study [10], we used Historical Weather Data on the state of environmental pollution and weather conditions of Basel city, which are freely provided for use by the owners of the Meteoblue system (Figure 8).

In order to better visually perceive and understand the threats to human health that are associated with AQI, a map generation module with color indication of AQI indicators was added to the IOT system (Figure 9).

A software application based on open APIs that analyzes sensor data and geolocation data of Smart-gadget and MGIS analyzes and generates messages about possible threats to human health, developed in the Python programming language [10, 26].

In order to evaluate performance, we conducted functional testing of the IoT system. In previous work, the performance of the IoT system was checked on various test data: geographic coordinates, state of air pollution, and concentration of pollen in the air [10]. In this work, the performance of the IoT system was checked on the test data provided by the Meteoblue system for Basel City (Figure 8) [18]. Basel city air temperature (2 m elevation corrected), wind speed (10 m), and relative humidity (2 m) were additionally analyzed in the system. Pressure (mean sea level) in Basel City has also been added to the message data [18].

As a result of the test, it was assessed whether the IoT system returns the expected result in response to the specified entered parameters [10].

The system showed a high efficiency of 100% on the specified test geographic data, various

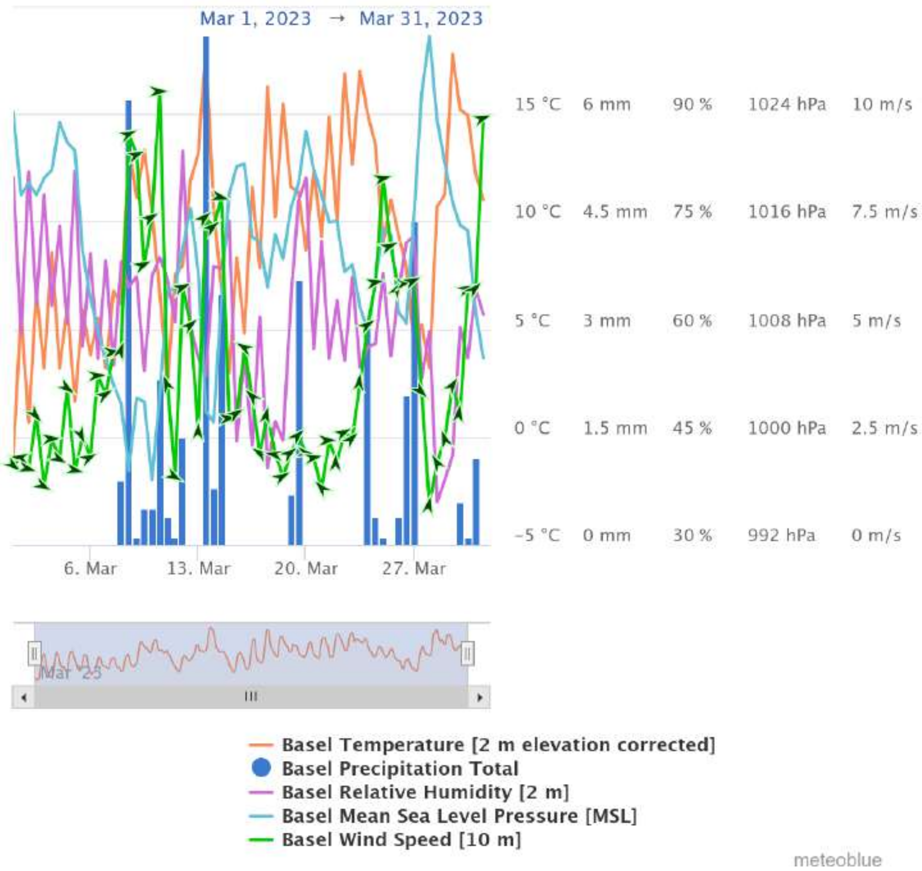

Figure 8: Historical Weather Data in Basel city, obtained using the Meteoblue system [18].

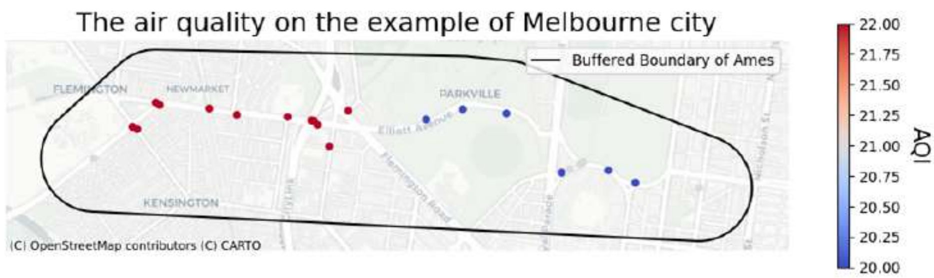

Figure 9: Map of historical AQI Data in Melburn city [2], obtained using the Meteoblue system [18].

parameters of the air pollution state [10], as well as city air temperature (2 m elevation corrected), wind speed (10 m), Relative humidity (2 m), including the limit parameters.

As a result of testing the IoT system according to the air quality index, it was determined that the MGIS Meteoblue [10, 18] system shows only an hourly "background" index [10, 18]. This IoT system does not define a "roadside" or "traffic" index [10, 18]. Therefore, as a result of its testing near highways, it was found that the system is not effective in use.

In previous work, data previously obtained from a similar Apple Watch 4 fitness tracker, which determines a person's geolocation, was used to test the system [10].

If there is pollen in the air (pollen grass, pollen birch, pollen olive), the system issues a message about this danger, indicating the pollen concentration level in the air [10]. The wind can increase pollen concentration in the air [10]. Also, the pollen becomes more allergenic if the air is polluted [10]. If the state of weather conditions, such as air temperature (2 m elevation corrected), relative humidity (2 m), and wind speed (10 m), do not meet the recommended norms, which should not cause health disorders in a "healthy" person, the system a warning message is generated. Also, in addition to other indicators about the state of human health and the environment, the pressure (mean sea level) indicator was added.

Using the developed IoT system can have preventive and, in some instances, therapeutic value (as prevention of disease exacerbations) [10]. This is necessary to prevent pathologies related to the state of the external environment, particularly the presence and concentration of substances that can be allergens (substances that cause allergies) [10]. It is essential to use the developed IoT system for the prevention of allergic diseases, including, first of all, pollinosis (diseases caused by plant pollen), as well as other pathologies in which an allergic component is present [10]. Among such disorders with an allergic component, we single out bronchial asthma. It is essential to prevent its attacks and exacerbations (the active phase of the disease that manifests itself against the background of relative well-being) [10]. Thus, bronchial asthma is presented not only as a medical but also as an ecological problem, the critical preventive aspect of which can be solved by the developed IoT system [10].

The recommended scales of the air quality index (dimensionless) and the European Common Air Quality Index (CAQI) were used to generate the messages [10, 18] (see table 1). Because we added the ability to analyze temperature, relative humidity, and wind speed to the results of the previous study, we adjusted the Air Quality Index (AQI) message by adding the abbreviation "AQI:" to make it clear to the user that this message refers to AQI (see table 1).

In this study, an analysis of temperature, relative humidity and wind speed was added to the results of the previous study (see table 3, table 2). When developing tables of indicator values, according to which the message is generated, generally accepted international and Ukrainian hygienic norms were taken as a basis [6, 31]. According to the current norms, a wind speed of up to 2 m/s is considered comfortable [6, 21, 31], we used the Beaufort scale to determine comfortable wind speed to generate a message (see table 4).

Air temperature, relative air humidity, and wind strength are among the system indicators of the state of the external environment, which determine the state of health and comfort of a person. At the same time, these indicators can be considered as limiting factors for a comfortable existence. Under the condition that these indicators go beyond the normative and optimal zone, they are considered systemic risk factors for the occurrence of human health disorders or exacerbation of existing pathologies.

According to the air quality index value, temperature, relative humidity, precipitation amount and wind speed, the system issues a message about possible threats to human health, if any, and recommendations for actions in this situation (Figure 10). This message is generated using test data about air quality and weather conditions in Basel [10, 18]. In addition to these data, when using this IoT system, the user receives messages about "Average heart rate in last 1000m:",

Table 1
The warning message that the user of the IoT system can receive on a smartphone according to the Air Quality Index (AQI) value [10, 19].

Air quality index	Air pollution	Air Quality Index warning message
0 to 50	Excellent	AQI: Neutral, without threats or health consequences.
51 to 100	Good	AQI: In the case of existing weather sensitivity, it is necessary to limit outdoor physical activity.
101 to 150	Lightly polluted	AQI: Slight irritations may occur, people with pathologies of the respiratory and cardiovascular systems should minimize outdoor physical activity.
151 to 200	Moderately polluted	AQI: Some irritations may occur, people with pathologies of the respiratory and cardiovascular systems should minimize outdoor physical activity.
201 to 300	Heavily polluted	AQI: In healthy people, the risk of developing diseases increases significantly. In people with diseases of the respiratory and cardiovascular systems, endurance in conditions of activity will decrease. It is recommended that individuals and elders stay indoors and minimize physical activity.
over 300	Severely polluted	AQI: A decrease in endurance for motor activity is determined in healthy people. Signs of irritation may appear and the risk of various diseases may increase. Sick and elderly people should minimize physical activity and avoid being outdoors. Healthy people need to minimize physical activity outdoors.

"Total steps:", "Steps in last 1000m:" [10].

Functional testing of the IoT system was conducted on various test data: geographical coordinates, state of air pollution, pollen concentration in the air, temperature, precipitation amount, relative humidity, and wind Speed. Based on the given test geographic data, various parameters of the state of air pollution and weather conditions, including the limit parameters, the system showed high efficiency [10]. However, as a result of testing the IoT system according to the Air quality index, it was determined that the MGIS Meteoblue system shows a "background" index; therefore, the system is not practical in use along with roads [10].

6. Conclusion

The IoT human health data monitoring system was designed, developed and improved to provide real-time operational alerts anywhere, taking into account meteorological data on likely threats to human health, as well as generating notifications about human sensory data (Total steps, Steps in last 1000m, Average heart rate in last 1000m) and the state of the surrounding environment (Pollen Birch, Pollen Grass, Pollen Olive, Temperature, Precipitation amount, Relative humidity, Wind Speed, Air quality index). The developed application based on open APIs using Smart-gadgets and meteorological GIS in the process of work generates a message

Table 2
The warning message that the user of the IoT system can receive on a smartphone according to the relative humidity (2 m elevation corrected) value [6, 31].

Relative humidity	Determination of relative humidity level	Warning message about relative humidity level
0% to 14%	Inadmissible	Relative humidity: Discomfort, dryness, and irritation of eyes and respiratory tract may occur. People with pathologies of the respiratory and cardiovascular systems should minimize physical exertion outdoors.
15% to 20%	Very low	Relative humidity: In some cases, discomfort, dryness, and irritation of eyes and respiratory tract may occur. It is recommended that people with pathologies of the respiratory and cardiovascular systems should minimize physical exertion outdoors.
21% to 30%	Permissible	Relative humidity: Physical discomfort may occur. In the case of existing weather sensitivity, it is necessary to limit physical activity outdoors.
31% to 60%	Optimal	Relative humidity: Neutral, without threats and consequences for health.
61% to 75%	Permissible	Relative humidity: Physical discomfort may occur. In the case of existing weather sensitivity, it is necessary to limit physical activity outdoors.
76% to 90% and up to 100%	Inadmissible	Relative humidity: Discomfort may occur, people with pathologies of the respiratory and cardiovascular systems should minimize physical exertion outdoors. Allergic reactions can be provoked or existing ones strengthened.

about the danger to human health related to the presence of pollen in the air (pollen grass, pollen birch, pollen olive), indicating its level concentrations in the air; the presence of air quality problems, if the air quality indicator exceeds the permissible standards; the presence of temperature problems, under the condition that this indicator goes beyond the normative and optimal zone; the presence of relative humidity problems, under the condition that this indicator goes beyond the normative and optimal zone; the presence of wind speed problems, if the air wind speed exceeds the permissible standards.

The IoT system for tracking data related to human health is aimed at preventing the problems of negative effects of environmental factors on human health, which is implemented by generating warning signals about possible threats and reminders to take actions aimed at preserving health. In order to better understand possible threats to human health, the IOT module of data visualization based on the terrain map with AQI indication is implemented in the system. The addition of such functions expands the possibilities of timely provision of concise and transparent information about probable risks and threats and, accordingly, represents an “anthropo-geo-sensory-digital” prerequisite for making effective decisions in the current situation [10].

Air temperature and relative air humidity are, first of all, factors that affect the state of

Table 3
The warning message that the user of the IoT system can receive on a smartphone according to the temperature (2 m elevation corrected) value [6, 31].

Temperature, C^0	Determination of temperature level	Warning message about temperature level
to 16	Uncomfortable	Temperature: Discomfort may occur, people with pathologies of the respiratory and cardiovascular systems should minimize physical exertion outdoors. Illness and exacerbation of diseases of the respiratory system, musculoskeletal system and peripheral nervous system may occur, as well as exacerbation of other chronic diseases.
17 to 18	Acceptable	Temperature: In the case of existing weather sensitivity, it is necessary to limit physical activity outdoors.
19 to 24	Optimal	Temperature: Neutral, without threats and consequences for health.
over 25	Uncomfortable	Temperature: Discomfort may occur, people with pathologies of the respiratory and cardiovascular systems should minimize physical exertion outdoors.

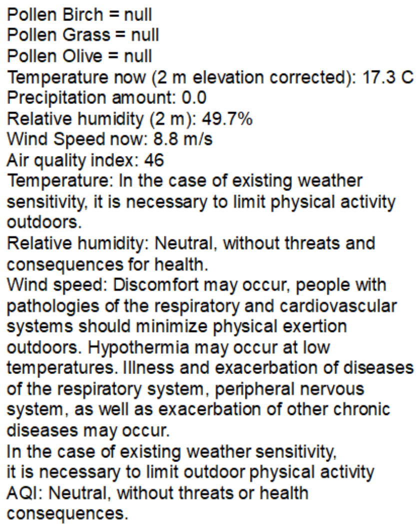
Pollen Birch = null
Pollen Grass = null
Pollen Olive = null
Temperature now (2 m elevation corrected): 17.3 C
Precipitation amount: 0.0
Relative humidity (2 m): 49.7%
Wind Speed now: 8.8 m/s
Air quality index: 46
Temperature: In the case of existing weather sensitivity, it is necessary to limit physical activity outdoors.
Relative humidity: Neutral, without threats and consequences for health.
Wind speed: Discomfort may occur, people with pathologies of the respiratory and cardiovascular systems should minimize physical exertion outdoors. Hypothermia may occur at low temperatures. Illness and exacerbation of diseases of the respiratory system, peripheral nervous system, as well as exacerbation of other chronic diseases may occur.
In the case of existing weather sensitivity, it is necessary to limit outdoor physical activity
AQI: Neutral, without threats or health consequences.

Figure 10: An example of a message that a user receives on a smartphone about possible threats to human health, if any, and recommendations for actions in this situation (12:00-17:59, March 7, 2023, Basel).

the cardiovascular and respiratory systems, which primarily support human life. The air's relative humidity, under its high values, can provoke allergic reactions or strengthen existing ones. Therefore, taking into account the factors mentioned above are primary and decisive for maintaining health based on the organization of a comfortable, physiologically optimal and acceptable existence, which includes the preservation of adaptive reserves of the body, as

Table 4
The message that the user of the IoT system can receive on a smartphone according to the wind speed (2 m elevation corrected) value [6, 21, 31].

Wind speed, m/s	Determination of wind speed level	Warning message about wind speed level
0 to 2	Optimal	Wind speed: Neutral, without threats or healthconsequences.
2.1 to 5.4	Acceptable	Wind speed: In the case of existing weather sensitivity, it is necessary to limit outdoor physical activity.
5.5 to 10.7	Uncomfortable	Wind speed: Discomfort may occur, people with pathologies of the respiratory and cardiovascular systems should minimize physical exertion outdoors. Hypothermia may occur at low temperatures. Illness and exacerbation of diseases of the respiratory system, peripheral nervous system, as well as exacerbation of other chronic diseases may occur.
10.8 to 17.1	Very uncomfortable	Wind speed: Discomfort may occur, people with pathologies of the respiratory and cardiovascular systems are not recommended to exercise. Hypothermia may occur at low temperatures. Illness and exacerbation of diseases of the respiratory system, peripheral nervous system, as well as exacerbation of other chronic diseases may occur.
17.2 to 24.4	Gale	Wind speed: Exercising outdoors is not recommended. Dangerous for human life and health.
24.5 to 32.6	Storm	Wind speed: Exercising outdoors is not recommended. Dangerous for human life and health.
over 32.7	Hurricane	Wind speed: Exercising outdoors is not recommended. Dangerous for human life and health.

well as through the prevention of pathologies of the cardiovascular, respiratory and immune systems (namely, allergic reactions), which can be formed relatively quickly and often against the background of complete well-being. Air temperature and relative humidity prevent chronic disorders and their exacerbations. This generally applies to all body systems and psychological health, including a positive emotional state and intellectual and creative abilities.

Functional testing of the IoT system was conducted on various test data: geographical coordinates, state of air pollution, concentration of pollen in the air, temperature, precipitation amount, relative humidity, and wind Speed. Based on the given test geographic data, various parameters of the state of air pollution and weather conditions, including the limit parameters, the system showed high efficiency [10]. However, as a result of testing the IoT system according to the Air quality index, it was determined that the MGIS Meteoblue system shows a "background" index; therefore, the system is not practical in use along with roads [10].

The IoT system has significant methodological and technological potential, which can be used to improve the effectiveness of health care, both in extreme conditions and in conditions of sustainable existence [10].

The practical significance of the research results is that the IoT system is developed to improve and increase the effectiveness of the human health care system, prevention of human health disorders (in extreme conditions, in conditions of sustainable existence), for example, during and after the COVID-19 pandemic; in the educational process of training and retraining of teachers of informatics, physical culture, ecology, health basics, doctors, rehabilitators, trainers; in practices and technologies of rehabilitation, medicine, ecology; in research on this topic; as one of the ways of introducing innovations in the IT sphere and the sphere of health care; in everyday life.

By providing real-time alerts about environmental hazards, the system can help people take preventive measures and avoid health problems related to allergies, respiratory, cardiovascular, and other human health problems. The proposed IoT system offers methodological and technological decisions to improve healthcare delivery by enhancing efficiency, enabling proactive prevention of health issues, and promoting personalized care. This could significantly improve public health, especially for vulnerable populations.

The improved IoT system can be actively implemented in a person's life, including physical education and sports, due to its complexity and integrative nature; when it is used, it is transformed into a particular cognitive "anthropo-geo-sensory-digital" system. This system provides qualitatively new opportunities for monitoring and analyzing health in real-time and using long-term monitoring data about environmental and body changes. Accordingly, it will be useful for healthy people and those at risk of new or aggravating and complicating existing pathologies. This is realized through the identification, analysis, representation, and preventively oriented interpretation of probable health risks, as well as managing them rationally and using typical and standardized algorithms and protocols. We consider the specified "anthropo-geo-sensory-digital" system as a component of an intelligent environment. It is "cognitive-anticipatory" in its managerial and preventive essence, capable of intelligent forecasting and modelling of the future. Thus, with the active application of this system, the social, cognitive, and socio-psychological potential of digital technologies is actualized, bringing society to a new cognitive-technological level of health preservation and life creativity.

In further studies, it is advisable to add Pressure (mean sea level) to the analysis of indicators about the state of the external environment and conduct a comprehensive analysis of the indicators considered in the work. Further research in this direction may be related to data processing in healthcare systems based on machine learning and deep learning [10].

References

[1] Ashraf, S., Khattak, S.P. and Iqbal, M.T., 2023. Design and Implementation of an Open-Source and Internet-of-Things-Based Health Monitoring System. *Journal of Low Power Electronics and Applications*, 13(4). Available from: https://doi.org/10.3390/jlpea13040057.

[2] CARTO, 2024. Modern spatial analytics built for the cloud. Available from: https://carto.com/.

[3] Centre for Science and Technology Studies, Leiden University, The Netherlands. VOSviewer, 2024. Available from: https://www.vosviewer.com/.

[4] Chatterjee, P., Tesis, A., Cymberknop, L.J. and Armentano, R.L., 2020. Internet of Things and Artificial Intelligence in Healthcare During COVID-19 Pandemic—A South American

Perspective. *Frontiers in Public Health*, 8, p.600213. Available from: https://doi.org/10.3389/fpubh.2020.600213.

[5] Chidambaranathan, S. and Geetha, R., 2024. Deep learning enabled blockchain based electronic heathcare data attack detection for smart health systems. *Measurement: Sensors*, 31, p.100959. Available from: https://doi.org/10.1016/j.measen.2023.100959.

[6] Edge, 2024. Healthy. Smart. Sustainable. Available from: https://edgesustainability.com/.

[7] Graham, C., 2021. Fear of the unknown with healthcare IoT devices: An exploratory study. *Information Security Journal: A Global Perspective*, 30(2), pp.100–110. Available from: https://doi.org/10.1080/19393555.2020.1810369.

[8] Klochko, O., Fedorets, V., Mudrak, O., Troitska, T. and Kaplinskyi, V., 2022. Modeling of ecophobic tendencies of consciousness of higher education students. *SHS Web of Conferences*, 142, p.03006. Available from: https://doi.org/10.1051/shsconf/202214203006.

[9] Klochko, O., Gurevych, R., Nagayev, V., Dudorova, L.Y. and Zuziak, T., 2022. Data mining of the healthcare system based on the machine learning model developed in the Microsoft Azure machine learning studio. *Journal of Physics: Conference Series*, 2288(1), p.012006. Available from: https://doi.org/10.1088/1742-6596/2288/1/012006.

[10] Klochko, O.V., Fedorets, V.M., Mazur, M.V. and Liulko, Y.P., 2023. An IoT system based on open APIs and geolocation for human health data analysis. *CEUR Workshop Proceedings*, 3358, pp.87–101. Available from: https://ceur-ws.org/Vol-3358/paper15.pdf.

[11] Klochko, O.V., Fedorets, V.M., Uchitel, A.D. and Hnatyuk, V.V., 2020. Methodological aspects of using augmented reality for improvement of the health preserving competence of a Physical Education teacher. *CEUR Workshop Proceedings*, 2371, pp.108–128. Available from: https://ceur-ws.org/Vol-2731/paper05.pdf.

[12] Konduru, P. and Naga Surya, S., 2020. IoT based Real-Time Pulse Monitoring and Geolocation Alerting System with Data Analysis. *International Journal of Engineering Research&Technology*, 9(9), pp.143–143. Available from: https://doi.org/10.17577/IJERTV9IS090050.

[13] Korenivska, O.L., Nikitchuk, T.M., Vakaliuk, T.A., Benedytskyi, V.B. and Andreiev, O.V., 2023. IoT monitoring system for microclimate parameters in educational institutions using edge devices. *CEUR Workshop Proceedings*, 3374, pp.66–80. Available from: https://ceur-ws.org/Vol-3374/paper05.pdf.

[14] Kravtsova, L.V., Zaytseva, T.V., Bezbakh, M., Kravtsov, H.M. and Kaminska, N.H., 2022. The optimum assessment of the information systems of shipboard hardware reliability in cloud services. *CTE Workshop Proceedings*. vol. 9, pp.200–215. Available from: https://doi.org/10.55056/cte.115.

[15] Kunal, Prakash, A., Avasthi, S., Agarwal, K. and Hussain, M., 2024. Modern healthcare systems: Unveiling the possibility of AIoT for remote patient monitoring. *Developments Towards Next Generation Intelligent Systems for Sustainable Development*, pp.180–203. Available from: https://doi.org/10.4018/979-8-3693-5643-2.ch007.

[16] Liu, J., Alo, R.A., Bautista, Y.J.P., Yedjou, C.G. and Theran, C., 2021. A Geospatial and ML-based Approach to Health Disparity Identification and Determinant Tracing for Improving Pandemic Health Care. *2021 Eighth International Conference on Social Network Analysis, Management and Security (SNAMS)*. IEEE, pp.01–08. Available from: https://doi.org/10.1109/SNAMS53716.2021.9731851.

[17] Malla, S., Sahu, P.K., Patnaik, S., Biswal, A.K. and Nayak, M., 2023. IoT-Enabled Smart Anti-Smog Towers: A Novel Approach to Urban Air Pollution Control. *Ingenierie des Systemes d'Information*, 28(6), pp.1479–1493. Available from: https://doi.org/10.18280/isi.280605.

[18] Meteoblue, 2024. Weather Archive Basel. Available from: https://www.meteoblue.com/en/weather/historyclimate/weatherarchive/basel_switzerland_2661604.

[19] Meteoblue, 2024. Weather Madrid (European Common Air Quality Index (CAQI), Particles, Gases, Pollen). Available from: https://www.meteoblue.com/en/blog/article/show/40150_Pollen+season+in+most+parts+of+Europe.

[20] Meteoblue, 2024. Weather Madrid (Temperature, Precipitation, Wind speed). Available from: https://www.meteoblue.com/en/weather/forecast/meteogramweb/madrid_spain_3117735.

[21] Meteo.ua, 2024. Beaufort scale. Available from: https://meteo.ua/ua/vocabulary/shkala-boforta-299.

[22] Mitchell, K., 2021. Internet of things-enabled smart devices, healthcare body sensor networks, and online patient engagement in COVID-19 prevention, screening, and treatment. *American Journal of Medical Research*, 8(1), pp.30–39. Available from: https://doi.org/10.22381/ajmr8120213.

[23] Nikitchuk, T.M., Vakaliuk, T.A., Chernysh, O.A., Korenivska, O.L., Martseva, L.A. and Osadchyi, V.V., 2021. Architecture for edge devices for diagnostics of students' physical condition. In: S.O. Semerikov, ed. *Joint Proceedings of the Workshops on Quantum Information Technologies and Edge Computing (QuaInT+doors 2021), Zhytomyr, Ukraine, April 11, 2021.* CEUR-WS.org, *CEUR Workshop Proceedings*, vol. 2850, pp.45–56. Available from: http://ceur-ws.org/Vol-2850/paper3.pdf.

[24] Pavitharani, G., Joy, R.T. and Rajendran, R.K., 2024. AI and IoT for universal health and well-being across generations. *The Climate Change Crisis and Its Impact on Mental Health*, pp.187–197. Available from: https://doi.org/10.4018/979-8-3693-3272-6.ch014.

[25] Pigliautile, I., Casaccia, S., Morresi, N., Arnesano, M., Pisello, A.L. and Revel, G.M., 2020. Assessing occupants' personal attributes in relation to human perception of environmental comfort: Measurement procedure and data analysis. *Building and Environment*, 177, p.106901. Available from: https://doi.org/10.1016/j.buildenv.2020.106901.

[26] Python Software Foundation, 2024. Python. Available from: https://www.python.org/.

[27] Raghuram, B., Srinivas, C., Venkatramulu, S., Rao, V.C., Vinaykumar, K. and Dulhare, U.N., 2023. A new smart communication protocol and Internet of Things (IoT) for waste Management System. *Journal of Theoretical and Applied Information Technology*, 101(24), pp.8156–8165. Available from: https://www.jatit.org/volumes/Vol101No24/12Vol101No24.pdf.

[28] Ryabko, A.V., Zaika, O.V., Kukharchuk, R.P. and Vakaliuk, T.A., 2021. Graph model of Fog Computing system. *CEUR Workshop Proceedings*, 2850, pp.28–44. Available from: https://ceur-ws.org/Vol-2850/paper2.pdf.

[29] Semerikov, S., Striuk, A., Vakaliuk, T.A. and Morozov, A.V., 2021. Quantum information technology on the Edge. *CEUR Workshop Proceedings*, 2850, pp.1–15. Available from: https://ceur-ws.org/Vol-2850/paper0.pdf.

[30] Tawhid, A., Teotia, T. and Elmiligi, H., 2021. Machine learning for optimizing healthcare resources. *Machine Learning, Big Data, and IoT for Medical Informatics*. Elsevier, pp.215–239.

Available from: https://doi.org/10.1016/B978-0-12-821777-1.00020-3.

[31] The State Standard of Ukraine, 2024. EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Available from: http://www.mathcentre.com.ua/download/dstu_en_15251-2011.pdf.

[32] Yesyrkenov, Y.E., 2008. *Dovkillia: Entsyklopediia suchasnoi Ukrainy (Environment: Encyclopedia of modern Ukraine).* NAN Ukrainy, NTSh. Available from: https://esu.com.ua/search_articles.php?id=20479.