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CYBER-PHYSICAL SYSTEM FOR MONITORING THE ENVIRONMENT FOR ALLERGENS USING GEOLOCATION DATA

The task of creating a cyber-physical system for monitoring the environment for allergens is relevant. Therefore, our study is devoted to the development of a method and a cyber-physical system for monitoring the environment for allergens using geolocation data.

The developed cyber-physical system for monitoring the environment for allergens not only uses the available information on the activity of pollen sources in a given region, but also measures the concentration of pollen in the air in real time, which helps to monitor the level of pollen in the region where the user is located, and, taking into account the user's geolocation data, provides him with useful information for route planning to avoid staying in high-risk areas. Collecting and analyzing geolocation data allows you to track changes in the distribution of allergens over time and in space. This can be useful for understanding trends in allergenic reactions and for developing effective allergy management strategies.

The cyber-physical system for monitoring the environment for allergens is useful for people with allergies by providing them with accessible and up-to-date information about the environment and the risks of allergic reactions, allowing them to better plan their activities and avoid areas with high levels of plant pollen concentration. Such a cyber-physical system enables an individualized approach to each user, taking into account their unique problems by performing allergen filtering. This allows for effective and personalized allergy management solutions. The proposed cyber-physical system can create a valuable database with allergic reactions and predictions that will be used to improve the methods of diagnosis, treatment and management of allergies.

The proposed cyber-physical system can be used for global monitoring of pollen and allergen levels in different parts of the world. This will allow us to identify global trends in the distribution of allergens and develop effective strategies for managing allergies at the global level.

Keywords: cyber-physical system, allergy, allergen, monitoring the environment for allergens, geolocation data, plant pollen sensors, pollen maps.

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КІБЕРФІЗИЧНА СИСТЕМА МОНІТОРИНГУ НАВКОЛИШНЬОГО СЕРЕДОВИЩА НА ПРЕДМЕТ АЛЕРГЕНІВ З ВИКОРИСТАННЯМ ГЕОЛОКАЦІЙНИХ ДАНИХ

Задача створення кіберфізичної системи моніторингу навколишнього середовища на предмет алергенів є актуальною. Відтак наше дослідження присвячене розробленню методу та кіберфізичної системи моніторингу навколишнього середовища на предмет алергенів з використання геолокаційних даних.

Розроблена кіберфізична система моніторингу навколишнього середовища не тільки використовує наявну інформацію про активність джерел пилку у заданому регіоні, але й вимірює концентрацію пилку в повітрі в реальному часі, завдяки чому допомагає відстежувати рівень пилку в регіоні, де перебуває користувач, а також, враховуючи геолокаційні дані користувача, надає йому корисну інформацію для планування маршруту з уникненням перебування у зонах підвищеного ризику. Збір та аналіз геолокаційних даних дозволяє відстежувати зміни в розподілі алергенів з часом та в просторі. Це може бути корисним для розуміння тенденцій зміни алергенних реакцій та для розробки ефективних стратегій управління алергіями.

Кіберфізична система моніторингу навколишнього середовища на предмет алергенів є корисною для людей з алергіями, надаючи їм доступну та актуальну інформацію про навколишнє середовище та ризики алергічних реакцій, дозволяючи їм краще планувати свої дії та уникати областей з високим рівнем концентрації пилку рослин. Така кіберфізична система надає можливість індивідуального підходу до кожного користувача, враховуючи його унікальні проблеми шляхом виконання фільтрації алергенів. Це дозволяє забезпечити ефективні та персоналізовані рішення управління алергіями. Пропонована кіберфізична система може створити цінну базу даних з алергічними реакціями та прогнозами, яка буде використовуватися для вдосконалення методів діагностики, лікування та управління алергіями.

Пропонована кіберфізична система може бути використана для глобального моніторингу рівня пилку та алергенів у різних частинах світу. Це дозволить виявити глобальні тенденції змін у розподілі алергенів та виробляти ефективні стратегії управління алергіями на світовому рівні.

Ключові слова: кіберфізична система, алергія, алерген, моніторинг навколишнього середовища на предмет алергенів, геолокаційні дані, датчики пилку рослин, карти пилку.

Introduction

An allergy is a cross-reaction of the immune system to substances that are not normally harmful to most people. An allergy is an overreaction of the immune system to something called an allergen. An allergen is a foreign substance that is harmless to most people, such as pollen or pet hair. But an allergic person's immune system tries to fight the allergen as if it were a germ or virus. The human body produces a protein called an antibody to fight the allergen. This is how a reaction to an allergen occurs - to pollen, various foods, subcutaneous injections, medications, various substances in the air, etc. Allergy symptoms can range from mild to severe and include itching,

rashes, swelling, coughing, red eyes, shortness of breath, and other symptoms [1-3].

Allergies can have a significant impact on a person's quality of life, especially if the symptoms are frequent or severe. To reduce the risk of allergic reactions, it is important to avoid contact with allergens. Avoiding what causes the allergy can help improve a person's condition, but this is not always possible, especially if the allergen is widespread in the environment, such as plant pollen [4-6].

A very common allergy is pollen allergy (hay fever), which is especially dangerous in conditions when plants actively produce their pollen. Pollen is often a direct or indirect factor in the seasonality of influenza-like epidemics [7]. Pollen allergies can affect a significant proportion of the population in many countries. The allergen content, pollen load, and symptoms of pollen allergy vary by region and year. Hay fever symptoms can be particularly pronounced in spring or summer, depending on when certain plants bloom and shed their pollen, and the pollen from specific plants is in the air in large quantities. It can be particularly pronounced in regions with a large number of plants that disperse their pollen [8, 9]. As for the plants that most often cause allergic reactions, these are usually herbaceous and woody plants. The most common allergens include pollen from woody trees such as maple, oak, and birch, as well as pollen from herbaceous plants such as timothy, wheatgrass, ragweed, etc. As a rule, there are 50 to 69 types of pollen in the air, depending on the season. From 24 to 27 types of pollen belong to woody plants and from 22 to 46 types of pollen belong to herbaceous plants [10].

In addition, a large amount of pollen causes not only allergic but also non-allergic diseases, for example, ragweed produces more reactive oxygen species, so it can cause inflammation, which leads to symptoms of upper and lower respiratory tract diseases even in people without allergic asthma, rhinitis or conjunctivitis [11].

According to the World Health Organization (WHO), approximately 10-30% of the world's population suffers from pollen allergy. Europe and other regions of the world have a high prevalence of this allergy. Pollen allergy affects a significant proportion of the European population and is believed to be on the rise [9]. In the United States of America, according to the National Institute of Allergy and Infectious Diseases, about 30% of adults and 40% of children are allergic to plant pollen [12]. The level of pollen allergy can vary depending on geographic location, the type of plants that grow in a particular area, and other environmental factors.

Doctors can diagnose pollen allergies using skin tests or blood tests. Treatment may include the use of antihistamines, inhaled corticosteroids, immunotherapy, and other methods [13-15].

Knowing the types of allergenic plants in a particular region can help people avoid contact with allergens and better manage their symptoms. Understanding this allows people to avoid unnecessary contact with allergens and take preventive measures. Thus, knowledge of allergenic plants in a particular region can be an important tool for managing allergic symptoms.

The public has a great interest in pollen counts and their predictions, as do many healthcare professionals in the allergy community. Many organizations and health institutes provide information on the types of allergenic plants in specific regions. For example, in the United States, the American Academy of Allergy, Asthma and Immunology (AAAAI) provides an online tool called the National Allergy Bureau, where you can find information about pollen levels in different cities and regions. The purpose of this program is to provide information on plant pollen levels to help people with pollen allergies plan their activities and avoid areas with high pollen levels. The National Allergy Bureau works with a network of air testing stations across the United States to collect air samples and determine the concentration of different types of plant pollen. This data is then analyzed and published online, where it is available for public use. Using the National Allergy Bureau tool, people can check pollen levels in their area and get information about which plant species are currently actively releasing pollen. This allows people to be more aware and manage their actions to reduce the impact of allergic reactions [16, 17].

There are also several mobile applications that help track pollen levels and predict peaks in allergic reactions, which helps to better plan user actions and avoid health problems. Here are some of them:

1) Pollen.com's Allergy Alert – the application provides daily pollen forecasts for a given region, including data on the pollen concentration of various plants, as well as forecasts of allergic reactions for a given region; the application allows users to receive up-to-date pollen and weather data, which helps them to better plan their actions and avoid allergic problems; the main functions of Allergy Alert are: daily pollen forecasts – information on pollen levels of various plant species for today and the next days, symptom monitoring – users can keep a log of their allergic reactions to track the impact of pollen on their health, allergic reaction forecasts – forecasts of allergic reactions based on pollen levels and other factors for better planning of actions by users, notification settings – users can set up notifications about pollen peaks and allergic reactions; thus, Allergy Alert is a useful tool for people suffering from pollen allergies, helping them to better manage their symptoms and reduce their impact on their daily lives [18];
2) Zyrtec AllergyCast – a mobile application designed specifically for people suffering from pollen and other allergens, which provides daily forecasts of allergic reactions, including information on pollen levels and weather conditions for a given region; the main functions of Zyrtec AllergyCast are daily allergy forecasts – the app provides daily forecasts of plant pollen and other allergens for a given region and weather data, plant pollen map – the app has a map showing pollen levels of different plant species in a given region to help users avoid areas with high pollen levels, symptom forecasts – the app

provides allergy symptom forecasts based on pollen levels and other factors to help users plan better, pollen peak alerts – users can receive alerts about pollen peaks to get an overview of the situation; thus, Zyrtec AllergyCast is also a useful tool for managing allergic symptoms and planning for people with allergies to pollen and other allergens [19];

3) WebMD Allergy – a mobile application of the well-known medical resource WebMD, which offers information about allergic reactions and pollen in a given region, as well as tips for managing allergy symptoms; the main functions of the application are: daily allergy forecasts – the application provides information on the level of plant pollen, allergens in the air and other factors that can affect allergic reactions for a given region, symptoms and treatment – the application contains information on the symptoms of various types of allergies and treatment recommendations, including advice on medication use and other symptom management methods, an allergy reaction tracker – users can keep a log of their allergic reactions and symptoms to track them and share with their doctor, allergen avoidance tips – the app provides tips on how to avoid contact with allergens and reduce the risk of allergic reactions; in general, WebMD Allergy is also a useful tool for those who face allergies, helping them to better understand their symptoms, manage them, and find effective treatments [20];
4) AccuWeather – one of the most famous mobile apps and websites for weather forecasting, providing users with weather information for today, the next days and even several weeks ahead, which also provides pollen level information and allergy forecasts; the main features of AccuWeather are daily allergy forecasts – the app provides information on plant pollen levels, allergens in the air, and allergy forecasts for a given region, pollen maps – the app can display a map of pollen distribution for a given region, helping the user to understand which allergens prevail in a given area and how this can affect their allergic reactions, Allergy alerts – the user can set up alerts for pollen peaks and allergic reactions to stay informed of the situation, Allergy management tips – the app can also provide tips on how to avoid contact with allergens and reduce the risk of allergic reactions; overall, AccuWeather is a handy tool that helps people with allergies better manage their symptoms and plan their activities depending on weather conditions and pollen levels in the air [21].

Obviously, there are other mobile apps for tracking pollen levels and predicting allergic reactions, but as we can see, they all have similar functions. However, the level of use of such applications has been and remains relatively low, especially in Ukraine, which is obviously largely influenced by potential users' perception of the price-benefit ratio, reliability, and accessibility [17, 22].

Of course, the more useful would be a cyber-physical environmental monitoring system that not only uses available and predictive information about the activity of pollen sources in a given region, but also measures the concentration of pollen in the air in real time, which would help to monitor the level of pollen in the region where the user is located, and, taking into account the user's geolocation data, provide useful information for route planning by the user to avoid high-risk areas.

So, the task of creating a cyber-physical system for monitoring the environment for allergens is relevant. Therefore, our study is devoted to the development of a method and a cyber-physical system for monitoring the environment for allergens using geolocation data.

Cyber-Physical System for Monitoring the Environment for Allergens Using Geolocation Data

Many studies have been devoted to the task of creating various cyber-physical systems, in particular, the studies described in [23-25].

To develop the above-described cyber-physical system for monitoring the environment for allergens, pollen maps in Ukraine will be needed for Ukrainian consumers. To do this, we will use the modeling of pollen distribution in Ukraine in terms of identifying regions with high pollen concentrations and the time when high pollen load occurs, which was carried out using the SILAM system, followed by mapping of pollen using the Grid Analysis and Display System, performed in [8]. The modeling results were compared and matched with aerobiological data obtained from six monitoring stations in Ukraine. In addition, the system under development will measure the concentration of pollen in the air in real time, which will help to monitor the level of pollen in the region where the user is located.

So, *the method of monitoring the environment for allergens* consists of the following steps:

9) training of the system – setting a set of threshold values for the pollen concentration of different plants $HPC = \{hpc_1, hpc_2, \ldots, hpc_n\}$, above which the system warns and notifies of a potentially high level of allergens; setting a set of threshold values for the pollen concentration of different plants $LPC = \{lpc_1, lpc_2, \ldots, lpc_n\}$, below which the level of allergens is considered low and safe;
10) collection of geolocation data – determination of the location of each plant pollen sensor using GPS trackers or other geolocation monitoring systems built into the sensors to create a map of allergen distribution in a particular region, determination of the location of the user of the mobile application of the cyber-physical system using the "Location" function of his mobile phone;
11) transfer of geolocation data to the server for analysis and processing;

12) formation of a set of indicators of pollen concentration values of different plants $PCM = \{pcm_1, pcm_2, \ldots, pcm_n\}$ based on data obtained from pollen maps characteristic of a particular region for the current date taken from the study [9]
13) transferring data on the pollen concentration of various plants in a particular region, collected from pollen maps, to a server for analysis and processing;
14) formation of sets of indicators of pollen concentration values of different plants in a given area $PC^1 = \{pc_1^1, pc_2^1, \ldots, pc_n^1\}$, $PC^2 = \{pc_1^2, pc_2^2, \ldots, pc_n^2\}$, …, $PC^m = \{pc_1^m, pc_2^m, \ldots, pc_n^m\}$ based on data obtained from *n* plant pollen sensors of the cyber-physical system located on one of *m* areas;
15) transferring data on the pollen concentration of various plants in a given region collected by the sensors to a server for analysis and processing;
16) analyzing geolocation data, data on pollen concentration of various plants in a given region, obtained from pollen maps and sensors of the cyber-physical system, using analytical methods for data processing;
17) creation of a map of allergen distribution in a certain region at a given time, available in the mobile application of the cyber-physical system, with a graphical display of the pollen level in a certain area;
18) allergen filtration by the user - selection of the plant(s), pollen of which causes allergies in the user;
19) if in a certain area of a certain region the level of pollen concentration of the *i*-th plant, selected by the user in the previous step, pcm_i, obtained from pollen maps, or pc_l^j, obtained from plant pollen sensors from *j*-th area, exceeds the corresponding threshold value of the pollen concentration of different plants hpc_i, then such an area is marked on the map in the mobile application of the cyber-physical system in red, and the user is given a warning and notification of high allergen levels in such an area of a particular region (for example, the one in which he or she is currently located);
20) if in a certain area of a certain region the level of pollen concentration of the *i*-th plant, selected by the user in the previous step, pcm_i, obtained from pollen maps, or pc_l^j, obtained from plant pollen sensors from *j*-th area, does not exceed the corresponding threshold value of the pollen concentration of different plants hpc_i, but exceeds the corresponding threshold value lpc_i, then such an area is marked on the map in the mobile application of the cyber-physical system in yellow as having an average level of allergens;
21) if in a certain area of a certain region the level of pollen concentration of the *i*-th plant, selected by the user in the previous step, pcm_i, obtained from pollen maps, or pc_l^j, obtained from plant pollen sensors from *j*-th area, does not exceed the corresponding threshold value lpc_i in a certain area of the defined region, such area is marked on the map in the mobile application of the cyber-physical system in green as having a low level of allergens and is safe for users.

Let's design a cyber-physical system for monitoring the environment for allergens using the proposed method. The architecture of the cyber-physical system for monitoring the environment for allergens is shown in Fig. 1.

Thus, the developed cyber-physical system for monitoring the environment for allergens collects geolocation data, collects pollen concentration values of various plants based on data obtained from pollen maps and on data obtained from plant pollen sensors of the cyber-physical system. Plant pollen sensors are specialized devices designed to detect and measure the level of pollen in the atmosphere. The following types of pollen sensors can be used: optical sensors – use light or infrared radiation to measure pollen levels in the atmosphere; electronic sensors – use electronic components such as pressure sensors, resistors, or capacitors to measure changes caused by the presence of pollen; biological sensors – use living organisms such as bacteria or plants to detect pollen; mechanical sensors – use mechanical means to detect pollen, such as filters or membranes that collect pollen from the

The data received by the cyber-physical system from various sources is transferred to the server for analysis and processing using analytical methods. Based on the analysis, a map of the distribution of allergens in a particular region at a given time is created with a graphical display of pollen levels in a particular area, which allows users to monitor pollen levels in their region and plan their actions to avoid contact with allergens during periods of high concentrations. The map is then made available to the user in the mobile application of the cyber-physical system, where the user can filter allergens - select the plant(s) whose pollen causes allergies. After the user selects the plant(s), the areas are colored red (high danger), yellow (medium danger) or green (safety) (graphical display of pollen levels using a color scheme) on the map of the defined region in accordance with steps 11-13 of the proposed method of monitoring the environment for allergens.

The developed cyber-physical system for monitoring the environment for allergens not only uses the available information on the activity of pollen sources in a given region, but also measures the concentration of pollen in the air in real time, which helps to monitor the level of pollen in the region where the user is located, and, taking into account the user's geolocation data, provides him with useful information for route planning to avoid staying in high-risk areas. Collecting and analyzing geolocation data allows you to track changes in the distribution of allergens over time and in space. This can be useful for understanding trends in allergenic reactions and for developing effective allergy management strategies.

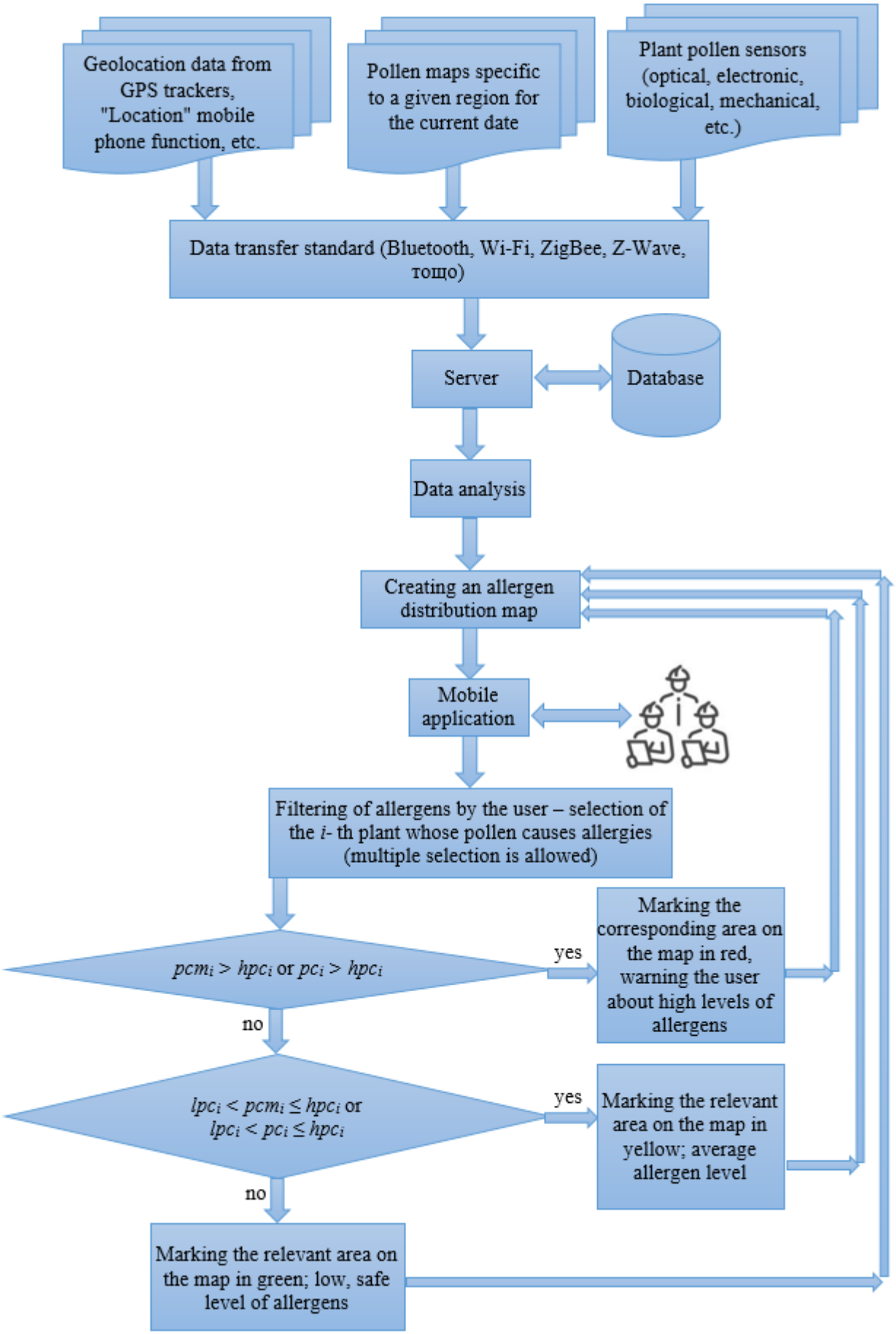

Fig. 1. Architecture of cyber-physical system for monitoring the environment for allergens using geolocation data

The cyber-physical system for monitoring the environment for allergens is useful for people with allergies by providing them with accessible and up-to-date information about the environment and the risks of allergic reactions, allowing them to better plan their activities and avoid areas with high levels of plant pollen concentration. Such a cyber-physical system enables an individualized approach to each user, taking into account their unique problems by performing allergen filtering. This allows for effective and personalized allergy management solutions. The proposed cyber-physical system can create a valuable database with allergic reactions and predictions that will be used to improve the methods of diagnosis, treatment and management of allergies.

The developed system can be integrated with other medical systems. Medical institutions can receive real-time data and take appropriate measures to treat and manage patients' allergic reactions. The data collected by the cyber-physical system can be used for scientific research in the field of environmental and ecological allergens. They can be used to improve diagnostic methods for allergic diseases, as well as to study the relationship between plant pollen levels and poor health. In case of a spike in the level of allergenic plant pollen, the system can automatically send warnings and recommendations to residents, medical institutions, and local authorities regarding the necessary safety measures. Thus, the proposed cyber-physical system can serve as a platform for collaboration between different stakeholders, such as healthcare professionals, researchers, authorities, and NGOs. This facilitates the exchange of data and knowledge, which allows for more informed and effective decisions in the field of allergy and public health. The proposed cyber-physical system can be used for global monitoring of pollen and allergen levels in different parts of the world. This will allow us to identify global trends in the distribution of allergens and develop effective strategies for managing allergies at the global level.

Conclusions

The task of creating a cyber-physical system for monitoring the environment for allergens is relevant. Therefore, our study is devoted to the development of a method and a cyber-physical system for monitoring the environment for allergens using geolocation data.

The developed cyber-physical system for monitoring the environment for allergens not only uses the available information on the activity of pollen sources in a given region, but also measures the concentration of pollen in the air in real time, which helps to monitor the level of pollen in the region where the user is located, and, taking into account the user's geolocation data, provides him with useful information for route planning to avoid staying in high-risk areas. Collecting and analyzing geolocation data allows you to track changes in the distribution of allergens over time and in space. This can be useful for understanding trends in allergenic reactions and for developing effective allergy management strategies.

The cyber-physical system for monitoring the environment for allergens is useful for people with allergies by providing them with accessible and up-to-date information about the environment and the risks of allergic reactions, allowing them to better plan their activities and avoid areas with high levels of plant pollen concentration. Such a cyber-physical system enables an individualized approach to each user, taking into account their unique problems by performing allergen filtering. This allows for effective and personalized allergy management solutions. The proposed cyber-physical system can create a valuable database with allergic reactions and predictions that will be used to improve the methods of diagnosis, treatment and management of allergies.

The proposed cyber-physical system can be used for global monitoring of pollen and allergen levels in different parts of the world. This will allow us to identify global trends in the distribution of allergens and develop effective strategies for managing allergies at the global level.

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