A Model of Cloud-Based System for Monitoring Air Quality in Urban Traffic Environment

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Abstract. Urban environments, with an ever-increasing population and ever-increasing traffic intensity, today represent a challenge for research and implementation of systems that would improve all aspects of life in such environments. These systems, based on smart technologies, are increasingly present in urban environments. The application of modern information technologies is the basis of these systems, and the application of cloud-based systems, which are key to the integration of systems and data, is particularly important. This paper presents a model of a cloud-based system for air quality monitoring in an urban traffic environment, with the main focus on software services deployed in the cloud. In addition to software services in the cloud, organized in service-oriented architecture (SOA), other relevant parts of the system with which these services communicate are also shown: the sensing layer, local area maps online service, online meteorological service, and a variety of web and mobile user applications. The main feature of the model, which contributes to its application in various environments, is that it is platform-independent, scalable and flexible for possible adaptations depending on proposed requirements.

Keywords: cloud · service-oriented architecture · air quality monitoring · urban traffic monitoring · smart city

1 Introduction

In the era of dynamic climate change and rapid technological development, air quality plays a very important role for human society and the environment, making monitoring of air quality and availability of measured data highly important. Due to the recognized various adverse effects of air pollution on humans, it is advisable to inform them about the spatial distribution of air quality, which should lead to the application of various measures

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to prevent or reduce unwanted impacts [1]. The use of these systems for monitoring air quality in urban environments leads to smart cities, which should consider several factors such as geographical complexity, population density, and the associated industry [2].

Cloud-based systems have been extensively used for the integration of heterogenous socio-technical systems in many areas of human life, leading to the improvement of systems quality attributes [3]. This trend has been recognized also in the fields of urban traffic management and air pollution management. The following issues and challenges should be considered when designing air monitoring systems [4]: design and maintenance costs, accuracy (data quality and precision), 3D Data attainment, active monitoring, flexibility and scalability, and power consumption. All these issues can be resolved to some extent, but in some cases, there is a need for a trade-off between some issues and challenges depending on the overall objective of the system, necessary infrastructure, computational complexity, and used development methods.

In the modern urban environment, the problem of air pollution represents one of the key challenges with a significant impact on people's health and the general quality of life. The increase in the number of vehicles and urbanization contribute to increased emission of harmful gases, thus emphasizing the need for effective air quality monitoring systems. In order to face this challenge, we present "A Model of Cloud-Based System for Monitoring Air Pollution in Urban Traffic Environment" - an innovative, platform independent and flexible cloud-based model that enables precise monitoring of air quality in urban traffic environment.

This model provides a holistic approach to solving air pollution problems, integrating Internet of Things (IoT) technologies, cloud and sensor networks to provide continuous and accurate analysis of harmful gas concentrations. Through the use of cloud-based architecture, the model provides fast and efficient access to data, which enables real-time monitoring and immediate response to changes in air quality.

This paper not only explores the technical aspects of the model, but also emphasizes its practical applicability in urban traffic environments. In addition, it provides insight into potential benefits for society, including improving public health, informing citizens about current air conditions, and providing relevant data to urban planners and decision makers.

In the following sections of this paper, we will explore in detail the key components of our model, the benefits of its implementation, and potential contributions to solving the ubiquitous problem of air pollution in urban traffic. This model not only promises effective monitoring, but also lays the foundations for creating a more sustainable and healthy urban environment for future generations.

Based on the above discussion it is evident that there is a permanent need to design new and improve existing systems for air quality monitoring, especially in urban settings with very intense traffic. In this direction, the objective of this paper is to propose a platform independent, flexible and scalable model of the cloud-based service-oriented system for monitoring air quality in urban traffic environments.

The paper is structured as follows. The second section outlines related studies in the field of air quality monitoring in urban areas. The third section presents a model of a cloud-based system, with a detailed description of software services deployed in the cloud. The final section contains a discussion, conclusions, and proposals for further work directions.

2 Related Work

In this section, recent studies about air pollution monitoring in cloud-based systems within urban traffic systems are presented. In general, the cloud layer in these complex socio-technical systems is mainly liable for processing data collected from various sources (although some processing of sensed data can be done in other layers) and interaction with users [5]. In some cases, cloud systems can be used only for presenting information, while all data processing is moved to other layers [6]. Implementation of the cloud layer is mainly based on services or microservices architectures [7].

Cheng et al. [8] presented design, implementation, and evaluation of client-cloud system for air quality monitoring. The system contains three layers: layer with monitoring stations, AQM cloud with air quality analytics, and user applications. The main component in the cloud is Air Quality Analytics Engine, used for processing collected raw sensor data. It contains offline training model and online calibration and inference models. The engine contains Artificial Neural Network (ANN) for online sensor calibration, Gaussian process for improving sensors' accuracy, and for inferencing values for locations where sensors are not available. User applications use data and analytics from the cloud. Some example applications enable getting real time values or time series stored in the cloud, trip planning based on the quality of air, or getting personal health record and recommendations. The system is open to be used or extended with additional use applications.

Fioccola et al. [9] presented a software platform designed for managing a set of Polluino devices that had been deployed for air monitoring. For implementation of cloud system, the authors provided in hors adopted Sensing as a Service model provided by ThingSpeak. Communication between cloud and IoT devices is based on REST API. The implementation is based on channels that are used for retrieving data from sensors. Data analysis and visualization is done with built-in MATLAB applications. Commercial solution IBM's Bluemix, based on Platform as a Service approach, is used since it supports majority of web-based technologies (Node.js, PHP, Go, and so on). In addition, the authors performed comparison of two communication approaches in the proposed system architecture, communication based on REST API and MQTT protocols. Results revealed that MQTT exhibits better performance, which will be considered in further research and development.

Idrees et al. [4] presented an air monitoring system with three layers architecture based on the edge-computing mechanism. The system layers are: (1) sensing layer – contains sensing nodes deployed over a wide area and responsible for sensing air quality, (2) edge computing layer – contains edge-computing devices responsible for communication between layers, and (3) application layer – contains services responsible for collaboration with users and operations with air quality data (storing, processing, and visualizing). Application layer contains data processing server, storage server, and HTTP server. User applications enable presenting air quality data (current status; trends over some periods like week or month; air quality indicators, recent events) in web application and mobile application. System functionality and reliability were tested with experiments in different settings, like rooms, offices, and open environments.

Guanochanga et al. [10] present the design and implementation of a three-layer architecture of a secure and low-cost air pollution monitoring system. The layers are: (1) sensing layer with the equipment for collecting air quality data and sending them to server, (2) application layer implemented in cloud for integrating, processing, and storing collected data, and (3) client layer for clients that use the system. The application layer is published in the cloud and contains MQTT Broker service for message-based communication with sensing layer. Collected data is published by using NODE-RED service, while No SQL database MongoDB is used for storing collected and processed data. The flow of data is performed by using RESTFUL Web services, which also enable sharing information with other systems. Client layer is implemented with graphical user interface that can be accessed via web browsers, from PCs or smartphones. Client layer enables presenting and visualizing information about monitored environmental parameters.

Arroyo et al. [11] proposed a system based on wireless sensor network and cloud computing for air quality monitoring. Measured data are transferred from sensors nodes (low-power ZigBee motes) to cloud through a gateway. Cloud system supports storing, monitoring, processing, and visualizing received data. Data processing is based on artificial intelligence methods such as a principal component analysis, a multilayer perceptron with backpropagation learning algorithm, and support vector machine. The cloud sensor network is composed by three different sections: a sensor network, a cloud system, and an end-user layer. Cloud system contains two layers: (1) the core layer – enables integration of components in service layer and integration of data, and (2) service layer – provides variety of services for other system components and users. Service layer contains services organized in several groups based on the functionalities they provide: (1) storage – connection, save, retrieve, and create services, (2) end-user – data visualization and request identification services, (3) sensor data – check and composition services, (4) e-learning – classify, train, and create services, and (5) security – access checking and user management services. The system is developed by using Rich Internet Application (RIA) technology, enabling access to services from web browsers through HTTP protocol.The system is tested in a laboratory case study.

A framework for managing air pollution and managing traffic police duty hours is presented by Jain et al. [12]. For this framework it is assumed that main most of the pollutants originate from static vehicle traffic while vehicles stop at a traffic crossing. Data about air pollution is collected by using sensors and IoT, while online data processing is performed at a cloud service Thingspeak. The designed system collects the following environmental parameters: CO2, CO, SO2, NO2, PM2.5, PM10, temperature and humidity. Based on calculations performed in MATLAB environment about exposure to pollution, traffic police are informed via email. REST API is used for communication between cloud system and IoT devices.

Evagelopoulos et al. [13] presented monitoring of environmental parameters with cloud-based system and over 55 air pollution monitoring stations located in Greece. The cloud-based system contains a set of applications that support collection of variety environmental parameters and reporting air quality accompanied with relevant meteorological data. System enables notification of relevant personnel and institutions. The main elements of the presented air data management system (AirDMS) are: (1) communication system – responsible for collecting data, (2) cloud-based information system. The components of cloud based system are: (1) web interface with desktop and mobile clients – used for disseminating information about collected data, (2) remote communication system – used for retrieving data, (3) AirDMS Service – used for instrumentation diagnostics, and (4) AirDMS Alerts system – used for sending alerts to authorized personnel in the case of problems with equipment or diagnosis of data that exceeds proposed limits. System is in the use in Greece, with data availability rates that exceed 99% during the year.

Asha et al. [14] designed automated Environmental Toxicology based Air Pollution Monitoring System based Artificial Intelligence technique (ETAPM-AIT). The costs and efficiency of the system are optimized by using IoT and cloud technologies. The sensing part of the system measures levels of MH3, CO, NO2, CH4, CO2, PM2.5, temperature and humidity, and transmits the values to the cloud. The system reports the state in real-time and sends an alarm if levels of some pollutants are exceeded. The classification of air pollutants and determination of the air quality is performed by using Artificial Algae Algorithm, while prediction is performed by using Elmann Neural Network. System performances are validated by using pollutant data, pointing out that proposed method outperforms existing methods.

3 Model

Our previous experience in designing smart systems for monitoring environmental parameters, such as edge computing system used for creating air pollution data center [15], a study of measuring road traffic noise, air quality, and vehicle frequency [16], monitoring and management of traffic noise [17, 18], and parking surveillance [19], pointed out the importance of designing flexible, scalable, efficient, and easy to implement cloud segment that enables system and data integration. In this course of thinking, the objective of this section is to present a comprehensive and detailed model of the cloud segment of a system for monitoring air pollution.

Further, a literature review of empirical studies about software architectures in traffic environments in the period from 2010 to 2021 revealed that the mostly used software architecture patterns are layered, service-oriented architectures, client-server, microservices, and distributed components [20]. These findings clearly guided us to choose a layered architecture for the whole system, while service-oriented architecture was adopted as the most suitable for the cloud part of the system.

Overall system architecture contains three layers, as is presented in Fig. 1. The layers in the system are: (1) Data source layer – represents various sources of data used for providing relevant data to be used in cloud services, (2) Cloud layer – contains services organized to perform required functionalities and store collected data for further processing, and (3) User applications layer – contains web and mobile applications available for users of information provided by the cloud system. The data source layer is divided into two segments: a layer with sensors and a layer that serves publicly available information for citizens.

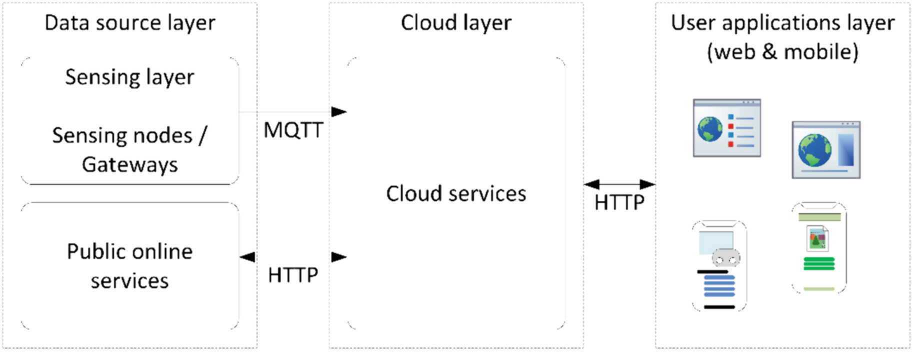

Fig. 1. Overall system architecture.

Communication protocols between layers are also presented in Fig. 1. Based on our previous experience with different types of equipment and applications in smart applications (traffic monitoring and smart factories) the choice of protocols is as follows: (1) Message Queuing Telemetry Transport (MQTT) protocol [21] is a lightweight solution suitable for communication between devices from low-power single-board computers to cloud services, and (2) HyperText Transfer Protocol (HTTP) [22] - standard protocol used for communication between web-based software applications and services.

Understanding the full set of functionalities organized as services in the cloud layer requires a short outline of the other two layers it communicates with, which is done in the following subsections.

3.1 Data Source Layer

Data source layers contain all potential sources of data to be used for gathering data used by software services located in the cloud layer. Two main segments, or sub/layers can be distinguished:

- Sensing layer with all sensor stations and communication equipment necessary to transfer collected data to software services in the cloud layer. This paper is focused on the description of data processing in the cloud, and data visualization in the use application layer. However, it is not in focus of this paper to describe the data transfer between sensor nodes, public online services, and end users with the core of the system (cloud layer). This layer contains sensing nodes and equipment grouped in two sublayers: Air Quality Sensing Layer and Traffic Sensing Layer.
- Public online services sublayer contains all services with publicly available data that can be used to accompany data collected in the sensing layer.

The Air Quality Sensing Layer and the Traffic Sensing Layer work together to provide a comprehensive picture of air quality in the urban traffic environment, which enables informed decision-making and reduction of the impact of air pollution on human health and the environment.

Air Quality Sensing Layer includes a network of sensors deployed throughout the urban area to accurately measure air pollution levels. In the proposed system, sensors measure concentrations of various pollutants, such as PM1, PM2.5, PM10, carbon monoxide (CO), carbon dioxide (CO2) and noise level measurement. Sensors send data to the cloud via a wireless or wired network. Data transmission is essential to ensure that air quality information is available in real time. Also, data processing and analysis is performed in this layer in order to identify trends, calculate average values and identify potential problems in air quality. Based on the analyses, the system generates alerts and notifications to inform competent authorities, citizens or other relevant parties about the current state of air quality.

Traffic Sensing Layer includes sensors that monitor the flow of traffic on roads. Various technologies, such as cameras, inductive loops or radar, can be used to collect data on the number of vehicles, speed and density of traffic. Collected traffic data is analyzed to identify traffic conditions. This data can be used to identify traffic congestion, identify key roads or intersections with problematic flow, and analyze the impact of traffic on air quality. Traffic data is integrated with an Air Quality Sensing Layer to understand the relationship between traffic and air pollution levels. This enables the identification of potential sources of traffic-related pollution. Traffic information can also be used to monitor mobility and identify areas subject to higher levels of air pollution.

Public online services are services available to citizens and contain information of general importance to society, such as meteorological information and geo-maps of local areas. Local area geo maps are important since they provide information about geographical objects and areas used by humans, such as areas with residential facilities, industrial areas, agricultural areas, areas with hospital facilities, or areas with facilities of cultural or historical importance. Meteorological parameters such as temperature, pressure, wind direction, wind speed, humidity, rain, and snow have a significant impact on the state of air quality, so it is necessary to download these data from public services (for example, the Republic Hydrometeorological Institute, or local institutions). Connecting meteorological parameters with data from geographical maps can be used for the calculation and prediction of air quality in certain regions of the inhabited place. For example, the wind direction from an industrial zone to a residential area can have an adverse effect on the air quality in that area, so it is necessary to calculate the air quality parameters, but also make a prediction in which time period these quality parameters will be valid.

3.2 Cloud Layer

The central part of the entire system is software services in the cloud that enable the integration of different parts of the system, data processing and storage, as well as services for various user applications.

The model at the level of software services placed in the cloud environment is shown in Fig. 2. The other two layers of the system are also shown in order to have a clear insight into the communication between individual services in the cloud with the environment.

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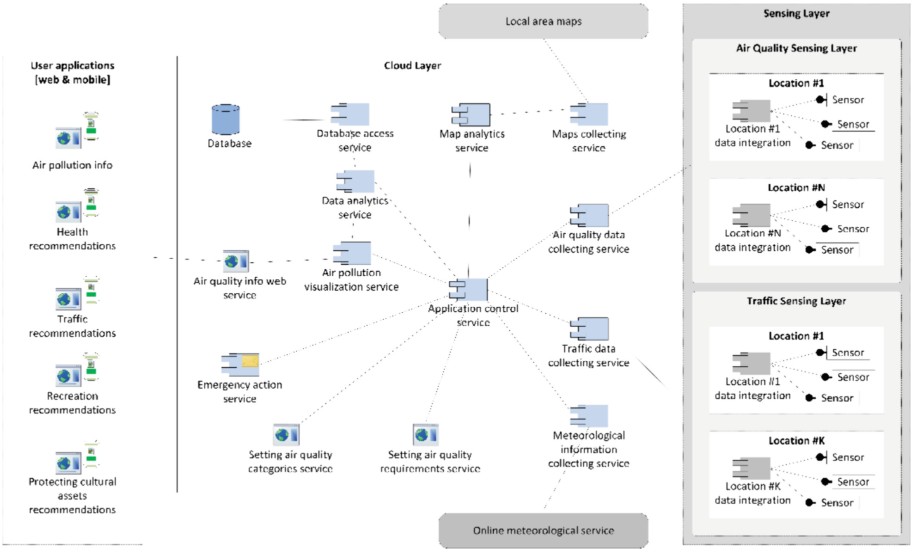

Fig. 2. Services deployed in the cloud layer.

The main component in the cloud layer is Application control service engaged in coordinating the work of all services deployed in the cloud. It connects services dedicated to collecting data from sensing layer and public services (meteorological services and local area maps) to other services dedicated to processing and storing data, gathering control input from users (setting air quality requirements, or setting air quality categories), and sending relevant information to user (individuals, groups of citizens, society as a whole).

Air quality data collecting service is a software component dedicated to collecting data from sensing layer that contains sensors for monitoring air quality in urban settings. Data is read from several measurement stations on a regular basis (one measurement in an hour). In cases where there is reasonable suspicion that there has been air pollution that can damage human health and/or the environment, dedicated measurements of the level of specific polluting substances must be carried out urgently. This information is sent to the system operator, and he sets up new urgent measurements. For receiving data is used MQTT protocol since it supports data format such as text data, binary data, XML [23], or JSON [24], which are flexible data formats commonly used in service-oriented cloud systems.

Traffic data collecting service is a software component dedicated to collecting data from sensors that monitor traffic in urban environments, particularly crossings where the frequency of vehicles is the highest. Like the component dedicated to collecting air quality data, this component also uses MQTT protocol.

Meteorological information collecting service is in charge of collecting data from online information services about meteorological conditions that might influence the quality of air. It collects data by using HTTP protocol, while data is structured in XML [23] format, which is suitable for further processing in service/oriented systems.

Maps collecting service collects geographic maps that are of interest to the selected urban area by using HTTP protocol, while Map analytics service is used for determining the sectors in the urban that are of interest for monitoring. For example, a typical division of the sectors is into residential areas, industrial areas, areas with health facilities, tourist attractive locations, etc. If these sectors and meteorological conditions are considered, the prediction of air quality in the neighboring sectors can be made for the selected sector (e.g. the spread of polluted air from an industrial zone to a residential zone).

Database access service implements all operations that require access to the database, such as storing data, updating data, deleting data, and retrieving data for further processing or presenting to users.

Setting air quality requirements service enables setting parameters for air quality, including all parameters relevant for monitoring. This includes limit values of the level of pollutants in the air, lower and upper limits of air quality assessment, critical levels for pollutants, and tolerance limits. This service is used by system operators, while the set values are used during device calibration and measurements of air quality parameters and traffic parameters.

Setting air quality categories service is a service used by system operators, aimed at setting air quality categories used for configuring measuring devices, processing measured data, data visualization, as well as calling emergency situations service (Emergency action service). The following categories can be set:

1. Category I (green) - clean or slightly polluted air where the limit values of the levels for any pollutant have not been exceeded,
2. Category II (yellow) - moderately polluted air where the limit values of the levels for one or more polluting substances are exceeded, but the tolerance values of none of the polluting substances are exceeded, and
3. Category III (red) - excessively polluted air where the tolerance values for one or more pollutants are exceeded.

Air pollution visualization service is a software component that visualizes raw measured data, or processed data based on historical records of measurements. In addition, visualization may provide an air quality state based on geo maps of the urban areas, and considering air quality categories and sectors in urban area, as it is presented in Fig. 3.

Air quality info web service provides relevant data on air quality in the selected urban area within dynamically created web pages (air quality data, geo maps, meteorological data, and predefined values for air quality). The created pages are publicly available and can be linked to local info portals. In addition, some relevant information can be emailed to different information channels, such as local radio and TV stations, internet portals of local government, local tourist organizations and local health institutions.

Emergency action service enables execution of activities related to situations when the concentrations of certain polluting substances are dangerous to human health. These activities presuppose urgent public information, and giving recommendations regarding the activities of people, especially the population that may be particularly vulnerable (e.g. people with specific chronic diseases).

The data collected by the sensors and from public online services is analyzed in the Data analytics service. This service must have the ability to analyze, first of all,

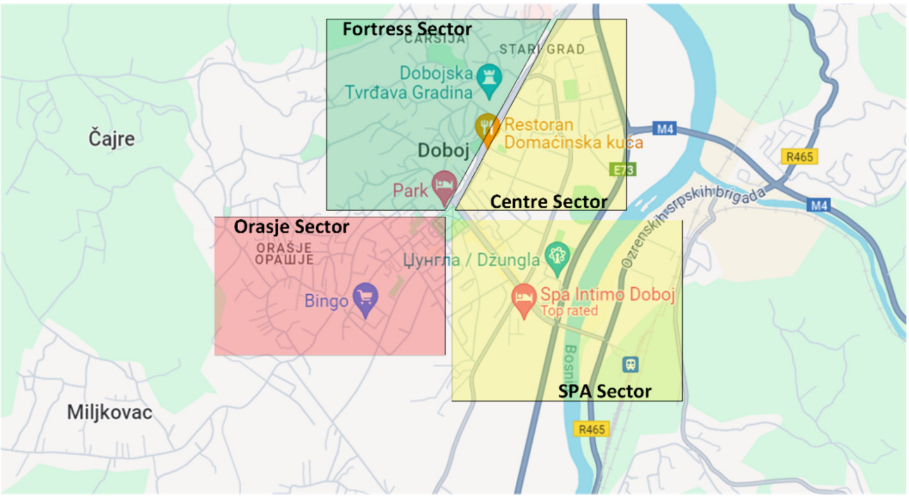

Fig. 3. Visualization of polluted areas in urban environments.

numerical data in order to carry out statistical analysis procedures, but also other data analysis techniques. The role of this service is twofold:

1. The service should provide the basis on which the Emergency action service will make a decision on the type of action and send the request to other services. This refers to the action based on the current state of air pollution, supplemented with weather and geographic location data.
2. This service should provide a prediction of the state of air pollution, based on the data read from the sensors, and weather and geographic location data.

The second role of this service is particularly interesting to consider, having in mind that the prediction of future conditions of air pollution can have a significant role in the type of decisions that are made, which are related to air pollution. The prediction of future levels of air pollution is related to individual points where the sensors are placed, and which data will be collected depends on the type of available sensors. For now, data has been collected regarding weather conditions and traffic conditions. Weather conditions are defined by measurements of wind strength, wind direction, temperature and humidity. Data on traffic conditions were obtained by measuring: the number of vehicles passing through the measuring point and the number of vehicles entering neighboring measuring points. The number of vehicles entering neighboring measuring points can be extremely important for assessing the load of a given measuring point in the future. In addition to the above data, data on the number of PM 2.5 particles were also collected using a sensor intended for this purpose.

However, in the process of collecting initial data for the purpose of calibrating the system and evaluating the prediction method, an increased influence of two parameters was observed: wind direction and number of vehicles. Bearing in mind that the distance of nearby sources of pollution and their intensity were not taken into account, this observation may not be crucial for the further development of the system. Nevertheless, it was decided that instead of a simple application of a neural network to generate a predictive model, this observation will be taken into account, so that the predictive model will be built in the form of ensemble machine learning [25, 26]. The scheme of the system is shown in Fig. 4.

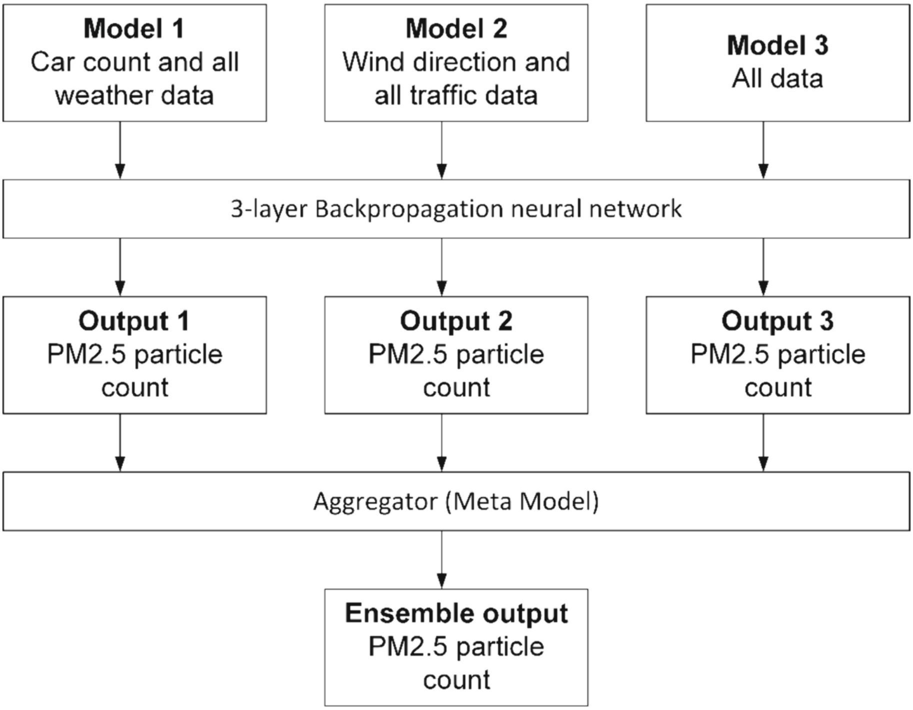

Fig. 4. Ensemble Machine Learning System.

Bagging was used as ensemble meta-algorithm for reducing bias and variance. Bagging enhances the performance if the algorithm used in learning the model is unstable, which is case because training set is small and partially synthesized. In this case, algorithm performs optimally because ensemble members have high variance and low bias. Final ensemble output is calculated by unweighted averaging of the outputs.

3.3 User Applications Layer

User applications are applications that can be used by citizens for various needs, such as information on the state of pollution of certain sectors (regions) in the observed area, receiving health recommendations, information on the choice of travel routes based on traffic conditions and air pollution, receiving recommendations for recreational activities, receiving recommendations on measures to protect cultural assets, etc.

User applications are based on recent web and mobile technologies, enabling the development of sophisticated and dynamic web and mobile applications. Customization of user interface design and accessibility for various stakeholders through responsive design should enable satisfactory user experience in real-time.

4 Conclusions

A model of a cloud-based system for monitoring air quality in an urban traffic environment is presented. The focus is on the services deployed in the cloud environment, while necessary elements of the whole system are presented to get full insight into the connection between software services in the cloud and other components in other layers. A detailed description of software services in the cloud is given, and special attention is paid to the data analytics service, the air parameter settings service in the observed environment, and the air pollution data visualization service.

Future work will be directed towards the development and testing of the whole system within the real setting in smart cities and experimentation with different data analytics approaches. Analysis of the whole system performances, or performances of some specific services under different loads and in various urban sizes will lead to increased system usability, reliability and effectiveness. The main aim is to enable better management of urban traffic, energy consumption, and urban planning to reduce pollution. Close cooperation with public services in urban areas, the implementation of the aforementioned services and the development of new ones, through the timely delivery of real data on air conditions, should contribute to improving the quality of life, traffic efficiency and environmental preservation.

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