Acquisition, storing, and processing system for interdisciplinary research in Earth sciences

Robert Brzoza-Woch[1] [0000−0002−8340−5454], Tomasz Pełech-Pilichowski[1] [0000−0003−2212−7806], Agnieszka Rudnicka[1] [0000−0003−3581−5608], Jacek Dajda[1] [0000−0002−8617−4981], Ewa Adamiec[1] [0000−0003−3207−4904], Elżbieta Jarosz-Krzemińska[1] [0000−0002−9654−1420], and Marek Kisiel-Dorohinicki[1] [0000−0002−8459−1877]

AGH University of Science and Technology, 30-059 Kraków, Poland

Abstract. The article presents the results of research carried out as part of the interdisciplinary cooperation of scientists in the field of geochemistry and computer science. Such a model of cooperation is justified and especially purposeful in resolving various environment protection tasks, including the issues of energy transformation and climate change. The research regards air quality monitoring case study conducted in Ochotnica, South Poland. The environmental data have been collected, stored, and processed using a set of sensor stations as well as a data storing and processing service. The stations and the service are very flexible, easily extensible, and they have been successfully designed, implemented, and tested by the authors of this paper in the mentioned air quality monitoring case study. The collaboration in the conducted research has been an opportunity to create and test in practice a comprehensive, versatile and configurable data acquisition and processing system which supports not only this use case, but also can be applied to a wide variety of general data acquisition and data analysis purposes. In this paper we discuss the analysis of acquired environmental data as well as a general approach to environmental data processing and visualization system.

Keywords: Environment protection · Data acquisition, processing and visualization · Internet of Things · Data analysis.

1 Introduction

Interdisciplinary cooperation between computer scientists and environmental geochemists provides a comprehensive and synergistic approach to solving scientific problems, i.e. regarding environmental protection or climate change.

1.1 Motivation

Air pollution is a global issue. It is extremely important and inextricably linked with premature deaths all over the world [9]. Poland is ranked as one of the

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

most air-polluted countries in Europe, according to WHO [14]. As a result, the inhabitants of the most polluted areas expect from the government more radical and effective measures, in particular regarding access to reliable and actual air quality data. This requires information acquired from densely placed air quality sensors. A larger number of sensors may generate more data [18], hence adequate storage, processing, analysis, and visualization capabilities are required to meet public expectations in assessing potential risk to human health and the environment. Moreover, all activities disseminating knowledge on environmental issues, through information and monitoring activities, indirectly help to build environmental awareness of the citizens and promote positive changes in the way of thinking, their decisions, as well as their everyday habits.

Considering the close relationship between air pollution, climate change and the issue of energy transformation, advanced data processing systems should be regarded as especially suitable for collecting and processing heterogeneous data thus obtaining information on, inter alia, potential sources of pollution. Consequently, this will allow for a quick and precise data analysis as well as the formulation of possible scenarios for planning and taking actions by municipalities. If the data processing system is advanced enough, those analyses can be to a large extent performed automatically. Moreover, the obtained air quality data can be further analyzed together with meteorological data, traffic intensity, and other parameters related to air emissions, in order to build local air quality forecasts models. Computer analysis of data allows to determine the trends in concentrations of pollutants in atmospheric air, to detect symptoms of possible air quality fluctuations, to show correlation between obtained data, or finally to perform any advanced analysis on individual components of the recorded data. Above mentioned features of air-monitoring systems should be suitable for the purpose of formulating remedial measures on the improvement of air quality, including promoting good practices, such as higher energy efficiency or replacement of home heating systems.

1.2 Available solutions

According to the available literature, the problems regarding a comprehensive approach to air quality monitoring systems require a combination of data processing systems as well sensors which operate in the field. Such systems often utilize multiple concepts known from Internet of Things (IoT) and Wireless Sensor Networks (WSN) [7, 25, 5]. Multiple papers address different approaches to data acquisition sensor front-end issues. Descriptions of an air quality data collection system design and realization can be found for instance in [23, 20, 10, 13, 1]. There is a variety of solutions with interesting specific features, e.g. measuring vertical changes in the air quality [11] or the collection of air quality data from static and mobile sensors [16].

A vital aspect of a data acquisition system is the approach to its general architecture and methods of data aggregation and processing. The system complexity depends on planned overall system functionality and computing capabilities of data sources. In a basic approach just two or three layers can be sufficient (as

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

e.g. in [2]): 1) a data source (e.g. a WSN), 2) a cloud infrastructure, and 3) an optional interface for end-users. When considering environment data acquisition systems which utilize resource-constrained and energy-efficient hardware platforms combined with short-range sensor communication, a hierarchical or layered architecture is often chosen, as described in for example [24, 6, 4].

The large-scale distributed data acquisition systems may produce significant amounts of data [18] which should be further processed in a central but not necessary centralized top layer part of the system. The architecture of the top layer, as well as its versatility, storage capabilities, and processing power are crucial for the implementation and application of advanced and useful algorithms, including prediction [22, 3], techniques which make use of machine learning (e.g. [21]), advanced data analysis, visualization, and data fusion [8, 15, 19].

2 The proposed solution

The solutions briefly described in Section 1.2 mostly lack a genuinely comprehensive approach to the problem of complete systems for data acquisition, advanced processing, visualization, and a support for decision making. Instead, those topics are usually implemented, studied, and described as separate concepts. In contrast, the authors of this paper present a general, complete, and comprehensive approach to an advanced environment monitoring system. The general concept of the system has been adapted to the use case of air quality monitoring in close collaboration with specialists in geochemistry. The comprehensiveness of the presented solution was achieved thanks to the fact that as part of the cooperation in our team, all layers required for environmental monitoring and decision support have been developed and implemented: from the hardware layer of inexpensive sensor stations, through their embedded software, to the central system for high level results aggregation, processing, and visualization.

2.1 General ideas of the data acquisition and processing system

The important practical aspect of the the described study was to collect air quality data obtained from the Ochotnica village, South Poland. Then the collected data could be visualized and further processed. The data acquisition has been done using air quality sensor stations designed and built by the authors of this article and additionally commercial sensor stations manufactured by Sensonar. Our sensors were initially calibrated and validated with the existing reference air monitoring stations in order to achieve reliable spatial and temporal resolution.

The data processing service is very flexible and allows for implementing multiple algorithms, visualization techniques, and automatic report generation. This, in turn, allows specialists and authorities to draw appropriate environmental conclusions necessary for applying further actions aimed at improving local air quality.

Fig. 1 shows a simplified diagram of the general architecture of the data acquisition and processing system, which has been developed and then adapted for the air quality monitoring purposes.

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

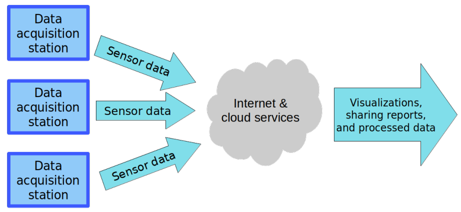

Fig. 1: A simplified diagram of a general architecture of the data acquisition and processing system.

The proposed solution uses versatile hardware and software platforms discussed further in this article. The solution can be used to facilitate individual decisions as well as to plan and implement a broader environmental policy, such as strategies for development and adaptation to climate change in cities, municipalities, and regions. The information flow for supporting the decision process, is presented in Fig. 2. The solution is based on a well-known approach: monitor-analyze-plan-execute with knowledge base (MAPE-K). We use the approach to implement a type of a feedback loop, which integrates environment and resource monitoring in order to facilitate the process of decision making by providing at least partially automatic data analysis. To provide input data, the proposed solution utilizes applied concepts of sensing and data transmission which are known from multiple IoT solutions.

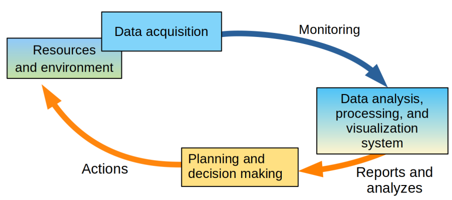

Fig. 2: The approach to the information flow in the proposed system.

The solution consists of the two initially mentioned subsystems which are to a large degree loosely-coupled and which may be used separately for different purposes as well. Further in this section we discuss important components of the system, mainly *DataHub*, which is responsible for general-purpose data storing, processing, and visualisation, and also *EnvGuard* which is the distributed sensor station system for environmental data acquisition.

2.2 DataHub

DataHub is a system primarily intended for *general-purpose* storage, processing, and visualization of data from various sources (also heterogeneous), processes and sets. It may perform advanced and specific analyses for different user groups.

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

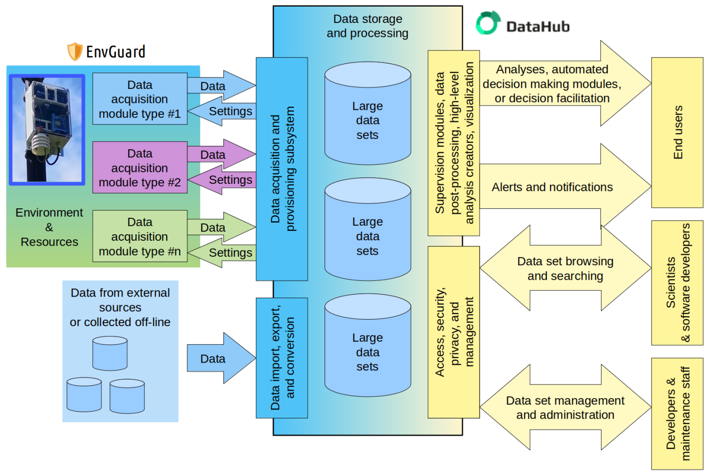

Fig. 3: The approach to the information flow in the proposed systems.

Its information flow block diagram and a sample usage context is presented in Fig. 3.

There are already available commercial solutions for similar purposes. However, their functionality and set of features may change, and they cannot be used to store very sensitive information without restrictive license agreements. That was the main reason to implement DataHub as our proprietary remote storage and processing system.

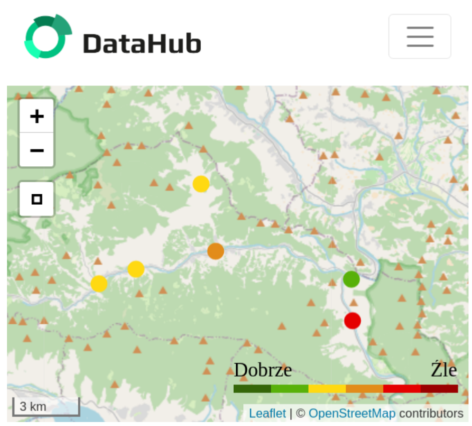

Fig. 4: View of the user-configurable map module for visualization of spatially distributed quantities (the GUI of the depicted map module is configured to display labels in Polish language).

The creators and developers of DataHub do not make any assumptions on data types to be supplied for the system. DataHub itself is also independent

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

from any particular use cases and purposes. The system uses generic data format, particularly JSON, for reading and writing information to and from its internal datasets. The DataHub interface is also equipped with import and export modules for interaction with external data sources.

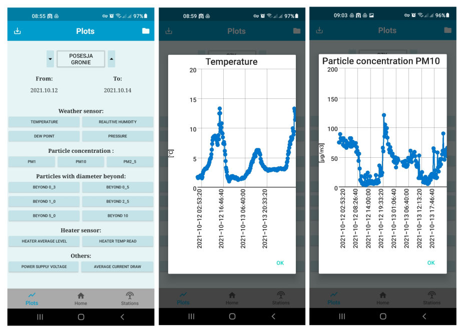

Fig. 5: Screenshots from the *AGH Stations* application for mobile devices.

DataHub functionality can be flexibly tailored to a wide variety of use cases, data types, and data processing methods, even in a large scale, depending on users' needs and proficiency. The customization of the DataHub data processing and visualization functionality can be done using several tools. General rule for the available tools is that the more technical knowledge and skills they require, the more use case-specific data processing and visualization can be achieved. This approach allowed us to create a system which can be operated by users with various specializations and roles. At the one side of this spectrum are regular end users who do not need any advanced technical knowledge and training. Those users may utilize generic built-in functionalities of DataHub to view data acquisition results or to set up basic visualizations. Modules for this group of users include built-in map visualization modules (Fig. 4).

Generic data interfaces of DataHub, such as a regular REST API and a basic Web interface, allow for accessing the acquired data from any device which supports communication over HTTP/REST. This simplifies implementation of custom applications and interfaces for data visualization using Web browsers and mobile devices. *AGH Stations* is one of such mobile applications. Sample screenshots of its user interface is shown in Fig. 5. The application is equipped with station configuration and deployment support functionality, so it is intended mainly for the technical and maintenance staff. However, its simplified basic version with limited features could be used by end users as well.

At the connection level, DataHub may require a secure connection to an internal institutional network.The connection can be established using a regular OpenVPN client. At the Web interface level DataHub also offers multiple levels of security. A user who can access the DataHub Web interface is by default also allowed to access data from endpoints configured as *public*. Data from such

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

endpoints can be read without a personalized account and without further restrictions, using HTTP GET requests. If a user has an individual account in the DataHub service, then they may gain higher privilege levels. Currently the access to DataHub can be granted for educational purposes on individually negotiated terms and conditions. Each dataset may have assigned a group of users: at any privilege level users may have a read-only access to datasets as well as a right to read and execute optionally attached Jupyter Notebooks. A higher privilege level allows users to modify the dataset and endpoint parameters, as well to upload new Jupyter Notebook scripts to be executed. The highest configurable privilege level is intended for persons who perform administrative and maintenance tasks in a dataset and who may manage permissions for other users within the data set.

2.3 EnvGuard air quality sensor stations

The EnvGuard air sensor stations' role in the system is that they acquire data from the environment, check the validity of the measured quantities, pre-process the data, and send them to the DataHub service. As an additional feature, the sensor stations are able to communicate with each other and also to acquire data from DataHub.

Sensor stations can be perceived as versatile rugged industrial-grade IoT nodes. Instead of cutting edge hardware solutions, we decided to use proven technological solutions for the highest possible long-term reliability. The sensor stations have generic and well-defined internal interfaces between components and for external communication. That feature allows the stations to be set up very flexibly, efficiently, and even ad hoc.

To create a dense network of sensor stations and potentially allow community to participate in air pollution measurement and mitigation, the stations should be implemented as possibly least expensive solution, yet still offering a satisfactory level of accuracy. In our case, the latter problem has been to a large extent mitigated by carefully selecting sensors with a performance as close as possible to certified reference stations.

A general block diagram of the sensor station is shown in Fig. 6. Common basic components of each station include a particle concentration sensor and an environmental conditions sensor which measures at least temperature, relative humidity, and, optionally, atmospheric pressure. The utilized particle concentration sensor module is a very popular and easily available unit, model PMS7003. It measures the concentration of PM10, PM2.5 and PM1 particles. The station can also be equipped in extension sensor modules e.g. for NO_2 or SO_2 measurement capability and a compatible generic interface commonly used in embedded systems and IoT such as I^2C. However we try to rely mainly on the basic dust particle concentration and weather condition sensors to keep the sensor stations' hardware overall cost at possibly the lowest level.

The communication module used to exchange information with DataHub can be flexibly chosen. We have successfully implemented communication using not only on-board Wi-Fi modules available in the SBCs but also generic industrial

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

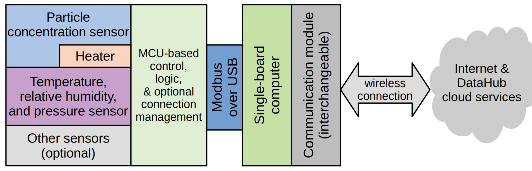

Fig. 6: A simplified general block diagram of the sensor station.

mobile network communication modules and LoRa wireless connection. The sensor station power demands are in practice up to approx. 1 W. This encouraged us to design a unique energy saving solution using a microcontroller (MCU). The MCU controls power supplies for all vital components of the sensor station while requiring very low power for itself, typically less than 50 µA in sleep mode. This way we achieved a very flexible power management subsystem providing either high computing power on-demand or extreme energy savings when needed.

All design-specific mechanical components of the designed sensor stations can be fabricated using a generic 3D printer. Moreover, the mechanical design of the station is optimized for low filament usage as well as quick and easy assembly in order to further decrease the stations' overall costs.

A sample sensor station intended and configured to operate in the EnvGuard system is depicted in Fig. 7. That particular station had been set-up in an inexpensive option with additional features which include UPS and mobile network communication.

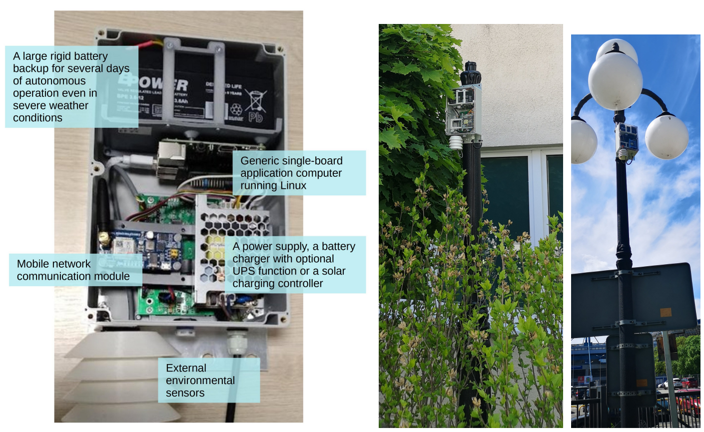

Fig. 7: View of the sample sensor stations for the EnvGuard system.

2.4 The conducted air pollution measurements

Until now, the presented data acquisition and processing solution has been successfully used for actual measurements of air pollution in as many as 20 locations. This article, however, focuses on selected 6 particular locations, which

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

Table 1: Air quality sensor stations location.

Location	GPS Lat.	GPS Lon.	GPS Alt.
1. Ochotnica Górna, Primary School	49.512690	20.248250	604.0
2. Ochotnica Górna, Private property	49.518179	20.271481	566.0
3. Ochotnica Dolna, Municipal Office	49.525603	20.320180	489.0
4. Ochotnica Dolna Młynne, Primary School	49.552233	20.310992	592.0
5. Tylmanowa, Primary School, Sucharskiego	49.497837	20.403642	392.0
6. Tylmanowa, Primary School, Twardowskiego	49.514682	20.402704	388.0

might require an attention. The following parameters: PM10, PM2.5 and PM1 dust particle concentration were determined in: four primary schools in Ochotnica Górna, Ochotnica Dolna and Tylmanowa villages, also on the building of Municipal Office in Ochotnica Dolna, and on a private property in that area. Detailed locations of sensor stations are presented in Table 1

For the purposes of this paper we analyze data from the period of 1 year until October 2021. The acquisition process has been done using EnvGuard custom sensor stations and additionally with one *Sensonar AirSense Extended* station. The additional Sensonar station has been used as a reference station. The Sensonar station, in addition to PM 1, PM 2.5, PM 10 particle concentrations and ambient temperature, can also measure the following parameters: carbon monoxide CO, nitrogen dioxide NO_2, and sulfur dioxide SO_2. The Sensonar AirSense stations meet the requirements of the international ISO 37120: 2014E standard for pollution in cities. The stations are certified according to the BS EN ISO 9001: 2015 standard for the design, production, sale and distribution of gas, chemical and physical sensors for industry and administration.

3 Results and discussion

Environmental data were collected from original air-monitoring sensors and then were processed and visualized with DataHub service. Sample graphs depicting research results, such as fractionation of PM dust, temperature and air humidity changes in selected measurement periods are presented in Fig. 8. Generating plots such as those is a relatively simple task when using DataHub, because DataHub supports direct execution of Python scripts from Jupyter Notebooks. In this particular case, a very popular *matplotlib* Python module has been employed to generate plots. Adequate software to execute Python code from Jupyter Notebooks is available directly on DataHub and it does not need to be installed on a user machine. The user is required to have only a generic Web browser and optionally a standard OpenVPN client.

Similarly, the users can implement various data processing algorithms relatively easily and effectively using multiple commonly available data processing modules for Python. Such additional modules can be easily included because the Jupyter Notebook execution environment in DataHub supports a flexible and on-demand installation process of additional modules imported in scripts.

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

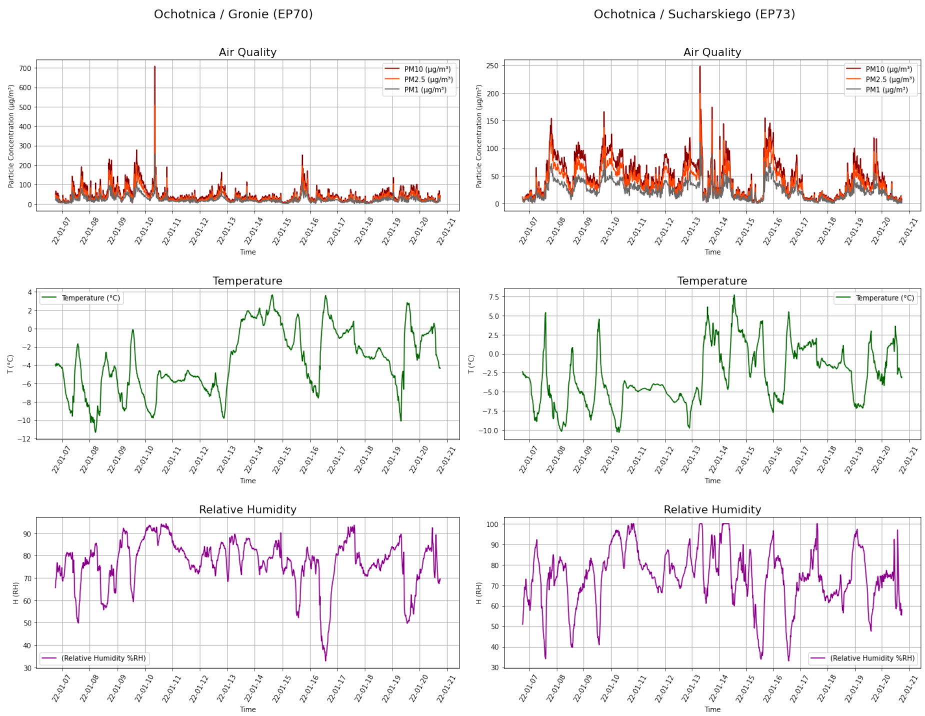

Fig. 8: Variability of physical parameters of ambient air over time.

This feature makes it easy to generate also other means to visualize data such as correlation matrices using *pandas* and *numpy*. Selected matrices generated from Jupyter Notebook for DataHub are shown in Fig. 9.

The correlation matrices in this case provided researchers with useful information about which weather parameters are related in particular stations. This, in turn, allows for easier choices of environmental policies and even long-term urbanistic strategy planning by local decisive persons. Moreover, all the plots and visualizations such as those presented in this section can be made available for regular users of the DataHub service, even those who have basic technical knowledge, and who may be interested mostly in measurement results and automatic reports.

In practice, DataHub platform, which has been designed and implemented by the authors of this article, was found to be flexible and universal in terms of various physical outputs. Moreover, it does not have geographical limitations. Information about DataHub parameters are included in Table 2.

3.1 Results analysis

This section contains an analysis of real-time environmental data using DataHub and formulation of recommendations for the residents and decision makers. One

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

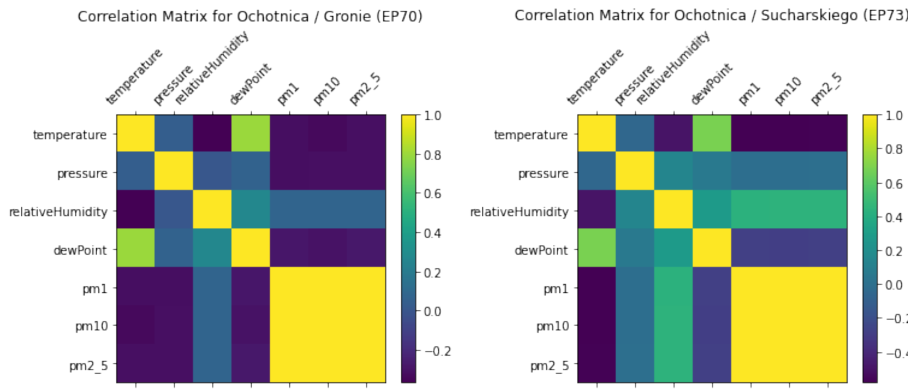

Fig. 9: Correlation matrices between certain physical ambient air parameters.

year real-time air quality data obtained from Ochotnica were processed via the DataHub service.

The acquisition, storing, and processing data from Ochotnica using DataHub service made it possible to determine the level of air pollution with such pollutants as: airborne dust, in particular PM 2.5, PM 10, PM 1, as well as CO, NO_2 and SO_2. The data for the described results have been acquired by both EnvGuard sensor stations as well as Sensonar reference stations, and they have been stored using DataHub service. The gathered data was a base for dedicated analysis of air pollution levels in the monitored area.

Table 2: DataHub settings and infrastructure parameters.

Parameter or a feature	Value	Explanation or additional information
Amount of data from API - currently being stored	38 GiB	As of January 20, 2022
Mass storage space for media & attachments	837 MiB	Includes readable information & attachments
Currently assigned maximum storage space for API data (PostgreSQL)	100 GiB	This parameter can and will be expanded according to the database storage space needs.
Maximum request size	16 KiB	Request size with request body excluded
Maximum number of requests	5000	Reloads workers after this amount of managed requests
Initial number of workers in separate processes	4	Increased automatically up to 8 (built-in load balancing mechanisms); can be manually set to a higher value
Virtual machine for running the DataHub service	2 vCPUs, 4 GiB RAM, 4 GiB swap, 1 TiB of mass storage	These parameters can be flexibly configured because DataHub works on managed virtual machines

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

Detailed data analysis allowed us to identify the possible sources of low-emission pollution and to identify the places with the highest potential health exposure risk for its residents. Studies have shown that, according to standardized Common Air Quality Index (CAQI), the air quality in Ochotnica Dolna can be classified as good or moderate quality on the majority of days, with a significant number of days classified as of moderate to sufficient air quality, and to a lesser extent of bad or very bad air quality. Correlation was found between the temperature drop in the evening and night hours and elevated concentration of dust pollutants in the ambient air. This is probably due to the increased demand for heat and simply extensive use of various kinds of solid fuels for combustion in home furnaces. Moreover, the impact of traffic-related air pollution was also observed in the morning and afternoon / evening hours, which was directly related to increased frequency of work and home travels. In Ochotnica Dolna, an increase in NO_2 concentrations was found in the morning and afternoon-evening hours, which may be related to increased car traffic in the vicinity of the City Hall and the intersection towards Ochotnica Dolna - Młynne. An increased concentration of CO was found in the morning and in the evening and night hours. However, no correlation was found between elevated concentration of CO and ambient air temperature dropping. High concentration of PM10, PM2.5 and PM1 was determined in the morning and evening hours, which may suggest, rather traffic-related source of its emission. In all analyzed locations, the permissible levels for PM10 and PM2.5 were exceeded in the evening and night hours (above 50 $\mu g/m^3$ for PM10 and above acceptable 25 $\mu g/m^3$ for PM2.5 [17] according to [12].

4 Conclusions and future work

The concept of the DataHub and EnvGuard systems presented in this paper emerged from the analysis of current literature, available solutions, as well as the expertise and the practical experience of geochemical scientists in cooperation with professional software developers, data analysts, as well as embedded and industrial IoT system engineers. We also closely cooperate with authorities interested in such systems in their respective regions and we have a very positive feedback on current DataHub and EnvGuard systems.

We have successfully developed concepts and practical implementation of the data acquisition, storage and processing solution. For users, developers, and scientists they facilitate data collection, storage, and processing with an emphasis on sharing and discussing the collected data sets and conclusions.

The novelty of our approach and research as well as our important contribution is the solution which addresses the important problem of air pollution in a very comprehensive way while in the reviewed available literature, authors usually concentrate on selected and specialized aspects of such systems. The resulting duo of the DataHub and EnvGuard systems has an ability not only to collect and store data acquired from the sensor stations, but also to facilitate the process of making decisions regarding environmental issues on the administrative level.

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

During our research and development collaboration as a team, we have successfully designed, built, and deployed the system which consists of DataHub service and includes more than 20 sensor stations. Most of the stations constantly acquire, process and transmit their results. The selected processing and visualization presented in this article are rather generic and simple. However, as future work related to DataHub, we are developing modules for automatic forecasting of air pollution using artificial intelligence solutions. We are also simultaneously working on (a) opening DataHub for an access for a larger group of users, and (b) a compact and even less expensive version of the sensor stations available for hobbyists and makers. We believe it may increase the popularity of the DataHub-EnvGuard systems and facilitate inclusion of community effort in the air quality measurements. That would contribute to the possibility of collecting air quality data on a larger scale and with a denser sensor network.

Acknowledgements The research by Robert Brzoza-Woch, Tomasz Pełech-Pilichowski, Agnieszka Rudnicka, Jacek Dajda, Marek Kisiel-Dorohinicki was partially supported by the funds of Polish Ministry of Education and Science assigned to AGH University of Science and Technology. The research conducted by Ewa Adamiec and Elżbieta Jarosz-Krzemińska was supported by AGH University of Science and Technology, Grant No 16.16.140.315.

References

1. Ali, H., Soe, J., Weller, S.R.: A real-time ambient air quality monitoring wireless sensor network for schools in smart cities. In: 2015 IEEE first international smart cities conference (ISC2). pp. 1–6. IEEE (2015)
2. Arroyo, P., Herrero, J.L., Suárez, J.I., Lozano, J.: Wireless sensor network combined with cloud computing for air quality monitoring. Sensors **19**(3), 691 (2019)
3. Ayele, T.W., Mehta, R.: Air pollution monitoring and prediction using iot. In: 2018 second international conference on inventive communication and computational technologies (ICICCT). pp. 1741–1745. IEEE (2018)
4. Bai, X., Wang, Z., Sheng, L., Wang, Z.: Reliable data fusion of hierarchical wireless sensor networks with asynchronous measurement for greenhouse monitoring. IEEE Transactions on Control Systems Technology **27**(3), 1036–1046 (2018)
5. Boppana, L., Lalasa, K., Vandana, S., Kodali, R.K.: Mongoose os based air quality monitoring system. In: TENCON 2019-2019 IEEE Region 10 Conference (TENCON). pp. 1247–1252. IEEE (2019)
6. Brzoza-Woch, R., Konieczny, M., Nawrocki, P., Szydlo, T., Zielinski, K.: Embedded systems in the application of fog computing—levee monitoring use case. In: 2016 11th IEEE Symposium on Industrial Embedded Systems (SIES). pp. 1–6. IEEE (2016)
7. Cynthia, J., Saroja, M., Sultana, P., Senthil, J.: Iot-based real time air pollution monitoring system. International Journal of Grid and High Performance Computing (IJGHPC) **11**(4), 28–41 (2019)
8. Deng, X., Jiang, Y., Yang, L.T., Lin, M., Yi, L., Wang, M.: Data fusion based coverage optimization in heterogeneous sensor networks: A survey. Information Fusion **52**, 90–105 (2019)

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36

9. EEA: EEA report no. 28/2016, air quality in europe - 2016 report. https://www.eea.europa.eu/publications/air-quality-in-europe-2016, accessed: 2020-01-20
10. Gryech, I., Ben-Aboud, Y., Guermah, B., Sbihi, N., Ghogho, M., Kobbane, A.: Moreair: a low-cost urban air pollution monitoring system. Sensors **20**(4), 998 (2020)
11. Gu, Q., R Michanowicz, D., Jia, C.: Developing a modular unmanned aerial vehicle (uav) platform for air pollution profiling. Sensors **18**(12), 4363 (2018)
12. Guerreiro, C., Colette, A., Leeuw, F.: Air quality in europe : 2018 report. European Environment Agency
13. Idrees, Z., Zou, Z., Zheng, L.: Edge computing based iot architecture for low cost air pollution monitoring systems: a comprehensive system analysis, design considerations & development. Sensors **18**(9), 3021 (2018)
14. IQAir: World's most polluted cities 2020. https://www.iqair.com/world-most-polluted-cities, accessed: 2020-01-20
15. Lau, B.P.L., Marakkalage, S.H., Zhou, Y., Hassan, N.U., Yuen, C., Zhang, M., Tan, U.X.: A survey of data fusion in smart city applications. Information Fusion **52**, 357–374 (2019)
16. Mendez, D., Perez, A.J., Labrador, M.A., Marron, J.J.: P-sense: A participatory sensing system for air pollution monitoring and control. In: 2011 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops). pp. 344–347. IEEE (2011)
17. Minister of the Environment: Regulation of the minister of the environment of 24 august 2012 on levels of some pollutants. Air Journal of laws of 2012, item 1031
18. Plageras, A.P., Psannis, K.E., Stergiou, C., Wang, H., Gupta, B.B.: Efficient iot-based sensor big data collection–processing and analysis in smart buildings. Future Generation Computer Systems **82**, 349–357 (2018)
19. Qi, L., Hu, C., Zhang, X., Khosravi, M.R., Sharma, S., Pang, S., Wang, T.: Privacy-aware data fusion and prediction with spatial-temporal context for smart city industrial environment. IEEE Transactions on Industrial Informatics (2020)
20. Raipure, S., Mehetre, D.: Wireless sensor network based pollution monitoring system in metropolitan cities. In: 2015 International Conference on Communications and Signal Processing (ICCSP). pp. 1835–1838. IEEE (2015)
21. ul Samee, I., Jilani, M.T., Wahab, H.G.A.: An application of iot and machine learning to air pollution monitoring in smart cities. In: 2019 4th International Conference on Emerging Trends in Engineering, Sciences and Technology (ICEEST). pp. 1–6. IEEE (2019)
22. Shaban, K.B., Kadri, A., Rezk, E.: Urban air pollution monitoring system with forecasting models. IEEE Sensors Journal **16**(8), 2598–2606 (2016)
23. Yi, W.Y., Lo, K.M., Mak, T., Leung, K.S., Leung, Y., Meng, M.L.: A survey of wireless sensor network based air pollution monitoring systems. Sensors **15**(12), 31392–31427 (2015)
24. Yu, T., Wang, X., Shami, A.: Recursive principal component analysis-based data outlier detection and sensor data aggregation in iot systems. IEEE Internet of Things Journal **4**(6), 2207–2216 (2017)
25. Zhang, H.f., Kang, W.: Design of the data acquisition system based on stm32. Procedia Computer Science **17**, 222–228 (2013)

ICCS Camera Ready Version 2022
To cite this paper please use the final published version:
DOI: 10.1007/978-3-031-08760-8_36