# Towards a smart city: An air quality monitoring system in Perheim

Henrik Lechte, Florian Finkel, Julia Grabinski, Cara Damm
University of Mannheim
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Master of Business Informatics
Email: {first name}.{last name}@mail.uni-mannheim.de

***Abstract*—**

## I. Introduction

Air quality is a topic which is facing much publicity due to its prevalence in law and media, especially regarding pollution laws leading to driving bans. Poor air quality caused by industry and daily life leads to health risks and adversely impacts the environment. Inhabitants of big cities are particularly affected by air pollutants, which might manifest themselves in smog or an industrial smell. Meanwhile, the concept of internet of things is on the rise, enabled by increased computation power, cost and energy efficient sensors and the availability of a fast cellular network.
Due to this, the city of Perheim may want to consider to implement an air quality information system based on a multitude of sensors in a connected network. Thereby, aggregated and location-based information about the current air quality can be provided.

## II. Existing approaches

It should be noted that measuring air quality as part of a smart city is no new approach, but has already been discussed in research [1] and has also been implemented in real-world projects. This shows that an air quality information system is a relevant topic. However, the concept for the city of Perheim is not directly based on one of these approaches. Existing research ranges for example from the application of low-cost crowd sensing sensors [2] to the combination of sensors with video monitoring of traffic [3] as well as using neural nets to predict future air pollution values [4]. Real-world projects include the *London Air Quality Network* (LAQN) launched in 1993 [5] and the so-called *Array of Things* in Chicago consisting of lamppost-mounted sensors [6].

There is also already a basic air monitoring system in place in the Rhein-Neckar area [7]. However, the new smart city air quality concept for Perheim differs in several aspects from the already existing system of the Rhein-Neckar area:

- The existing air monitoring consists of very few sensors per area. However, the approach propsed in this paper makes use of a higher number of small sensors to enable fine-granular monitoring.
- A new interconnected approach also allows for futher integrating more sophisticated smart city concepts regarding automatic traffic diversion and health care in the future.
- Currently, the measurements are not easy to consume. With live monitoring and an intuitive user interface, the visibility of the current status of the air quality will be greatly improved for citizens.

## III. Use cases

Monitoring the air quality and providing real-time information might prove useful in differerent use cases. It is also important to note that air quality is a very relevant topic for the city of Perheim. Perheim's downtown area is heavily frequented by cars. Furthermore, one of the world's biggest chemical companies, whose emissions and increased risk of toxic accidents and fires might also adversely impact the air quality, is headquartered in the neighboring city.

Each of the following use cases can be enabled by an air quality information system. The required technology and sensors will be covered in chapter V.

### A. *Managing health risks*

With an air quality information system, citizens can base their decision of when to leave the house or where to go for daily-life activities on the air quality. This might prove to be especially helpful for people with severe allergies or other adverse reactions to air pollutants. Also, health institutions can use the data and the home address of a patient to possibly correlate health issues with air pollution and thus providing more precise diagnosis. The air quality information system can also be used to give direct feedback in case of an acute risk by wildfires or leaks at chemical plants. In both cases it is usually recommended to stay inside. Negative health risks resulting from a high concentration of some air pollutants are summarized in a report carried out by the World Health Organization and are as follows [8]:

$O_3$ Long- and short-term excessive ozone exposure can lead to respiratory diseases and restrictions in activity.

$NO_2$ Nitrogen dioxide exposure can lead to bronchitic symptoms in asthmatic children as well as an increase in all-cause mortality.

$PM_{2.5}$ Long-term effects of excessive exposure to particulate matter of 2.5 micrometers or less can be cardiovascular diseases, lung cancer and an increased all-cause mortality.

$PM_{10}$ Inhaling particulate matter of 10 micrometers or less may result in asthma symptoms in asthmatic children and chronic bronchitis.

Apart from these major air pollutants, there is a wide variety of other air toxics which may cause cancer, respiratory reactions or other diseases [9].

It is also possible to build on the air quality information system by integrating the generated data into other technical devices. For example, windows could be automatically closed, air filters regulated and car navigation systems could propose routes based on the air quality. However, this is out-of-scope for a first technical implementation in Perheim.

### B. Environmental damage

Poor air quality not only impacts human health, but also the well-being of animals and plants. While the population of economically valuable insects can decline due to poor air quality, it could be observed that certain types of unwanted insects benefit from air pollutants [10][11]. The presence of air pollutants also reduces plant growth [12]. One of the major factors for this dynamic was sulfor dioxide causing acid rain. However, the sulfor dioxide emissions declined by 90% in Germany since 1990 making this not as much of a problem as it was three decades ago [13].

However, there is still a multitude of other pollutants affecting the environment [14][15].

In this context, the air quality information system can be used to investigate changes in the eco-system, to monitor the impact of the location of plants and roads and to find suitable locations to grow organic food.

### C. Enabling law execution

The impact of poor air quality on health and the environment has also been recognized by law makers. There are several laws governing the air pollution for industry and car traffic. The most important EU directive is 2008/50/EC [16]. This directive provides legal limit values for certain pollutants such as particulate matter, nitrogen dioxide and carbon monoxide. An air quality control system can help to monitor these limits, take action when needed and control their execution. Unusual or extreme measurements also hint on law breaches for example in form of illegaly operarted facilities that are subject to approval. In this case, the local municipality is allowed to take action in compliance with §20 and §62 of the Bundes-Immissionsschutzgesetz (BImSchG) [17]. In a more advanced smart city approach, the fine-granular air quality information will be integrated with automatic traffic control. Thereby, automatic speed limits and the diversion of cars from heavily to less frequented areas and streets help to satisfy required pollution limits.

### D. Psychological effect

Having a direct and real-time exposure to air quality data might result in an increased ecological awareness of citizens. Thereby, a voluntary switch from e.g. coal energy to a renewable energy provider or from environmental-unfriendly cars to electric vehicles might be initiated. In the same context, Perheim receives an image boost, showing the city as being environment friendly and digitally advanced.

## IV. Economic feasability

While the initial cost of sensors is not expected to be exceptionally high, maintenance and installation must also be accounted for. Several different models for covering the costs are possible.

### A. Tax-payer funded service

In the most straight-forward approach, the local municipality and thus indirectly the tax payer is responsible for buying and installing the sensors. The service is then provided to all citizens of Perheim free of charge. This is a sensible idea because not only do the citizens benefit from the air quality information system, but also the municipality itself. Furthermore, it does not require the citizens of Perheim to take action. Therefore, this is the recommended approach.

### B. Subscription-based service

Like other cloud and internet of things services, the air quality information could be provided as a subscription for a small fee of a few euros per month. However, this bears the disadvantage that most people might not be interested in the service or do not consider the price-value ratio as attractive. It could also be possible to keep some measured values free and enabling additional information based on more specific sensors for a small fee. As discussed before, an air quality information system could be used as a foundation for other products such as smart home devices and health care software. Therefore, a seperate subscription for commercial use might be reasonable.

### C. Voluntary contributions

The sensors could also be sold to the citizens at a discount. Thereby, Perheim's inhabitants can contribute voluntarily by buying the sensors and installing them outside their home. Through this model, a fine granular network can be achieved and the city only needs to cover the costs for the discount and servers. However, this approach relies entirely on a wide participation rate in the population.

### D. Data as a product

Historical and live data might be interesting for companies and researches. Selling complete data sets might complement one of the other models.

## V. Technical implementation

In terms of technical implementation of the first generation of an air quality information system, the goal is to reduce costs and keep the technical aspects simple. Therefore, the air quality sensor will be built using an Arduino and multiple other sensors. Afterwards, numerous of these air quality sensors will be installed in Perheim. Following the installation, the measured data is loaded into a central database and displayed in an easy to use and visually appealing application. The following chapters will cover a possible implementation of each of these steps in detail.

### A. Building the air quality sensor

First of all, it has to be determined what the final air quality sensor should measure. The European Union defined the European Air Quality Index (EAQI) in 2017 and it is similar to most of the Air Quality Index from other governments around the world, like the U.S. Environmental Protection Agency (EPA). It provides a set of air quality index levels: good, fair, moderate, poor and very poor. Furthermore, it defines multiple components, such as ozone, particulate matter, sulfur dioxide, carbon monoxide and nitrous oxide, that are getting measured and it provides a table to calculate the EAQI with the measured data of these components. Since the EAQI covers most of the important pollutants and is used throughout Europe, it will serve as the basis for the air quality sensors in Perheim (Germany). As the goal is to distribute a multitude of air quality sensors in Perheim, the first generation of air quality sensors will be built with inexpensive sensors to make them more affordable. In a later stage, when the developed system proves to be useful, sensors can be more expensive and of higher quality. With the focus on reducing the costs, the following sensors will be used for the first-generation air quality sensors:

- Ozone: *SainSmart MQ131*
- Particulate matter: *Grove Dust Sensor*
- Sulfur dioxide: *Mq2 Gas Sensor*
- Carbon monoxide: *Mq9 Gas Sensor*
- Nitrous oxide: *MICS-2714*

With these sensors all the components of the EAQI can be measured. Other important factors that play an essential role to the severeness of the EAQI are the current temperature and humidity. This is why a temperature and humidity sensor will also be integrated into the air quality sensor to improve the calculations. In the first iteration the *SODIAL - Temperature and Relative Humidity Sensor* will be used. Another important feature is, that the final application has to use the location of each sensor to display the measured data at the corresponding site. Therefore, each air quality sensor will be equipped with a *NEO-6M GPS* sensor to send the Global Positioning System (GPS) coordinates of its location with each measured data set. At last, the internet module *FONA Mini Cell GSM Breakout SMA* will be utilized to connect the Arduino to the internet and send the measured sensor data to a central system for further processing. All these hardware components will be soldered to a soldering board and thereby connected to the Arduino. The final construct will be placed in a weatherproof box that has three cutouts. A 5-Volt fan will be placed in the first cutout to blow the air through the box, along all the sensors and finally out of the second cutout. The third cutout is for a power supply for the Arduino. All initial air quality sensors will be manufactured using the procedure. The estimated cost of one sensor without the box is approximately 150 €. The required Arduino coding to read all the measurements is not part of this document.

### B. Creating a backend to process incoming data and managing already placed air quality sensors

The backend system that provides an application programming interface (API) for each interaction type with both air quality sensors and the frontend application will be covered in this section. These APIs can be implemented in many ways, e.g. as a Representational State Transfer (REST) APIs or as a create, read, update, and delete (CRUD) APIs, but the detailed implementation of these APIe won't be discussed in this document. The first API will receive the sent measurements of the air quality sensors and will provide the following functionalities:

- Receive a set of data containing the measurements, a timestamp and location from a sensor in JavaScript Object Notation (JSON) format
- Save received data into a persistence as one tuple of the corresponding database table
- Error handling in the event of wrong message formats
- Propagate crucial information if sensor measurements could be hazardous to health
- Authorization and authentication checks for each request

Moreover, the backend will also provide another API that sensors can poll from to retrieve the current interval time for sensor measurements. In case of numerous distributed sensors this API will make it easy to adjust said interval and avoid unnecessary manual labour. It will provide these features:

- Accept GET requests and return the currently set measurement interval
- Accept PUT and POST request to set a new measurement interval
- Error handling in case of a wrong request format
- Authorization and authentication checks for each request

With the two APIs defined before all the required interactions between each air quality sensor and the backend can be achieved.

Since these two backend endpoints should provide authorization and authentication checks, a corresponding security system has to be implemented. For the first generation sensors the widely established open standard OAuth 2.0 will be utilized. Therefore, the backend system will provide an authorization server that returns access tokens for the sensors. When a sensor is build the OAuth client credentials flow has to be performed manually to retrieve an access token for the new sensor. After receiving the token it will be hardcoded into the sensor which will in return send this token in each of its measurement requests as authorization header. Figure 1 illustrates this concept in a simplified representation.

Usually OAuth access tokens have an expiration date but for the first generation sensors each token can be used for an unlimited time period. In a later implementation phase the security concept should be reworked since the manual set up is tedious and using an access token for a prolonged time may result in security vulnerabilities. Such a security rework could include an oauth credentials flow automation where each sensor retrieves itself new access tokens in a set time intervalA without manual working steps.

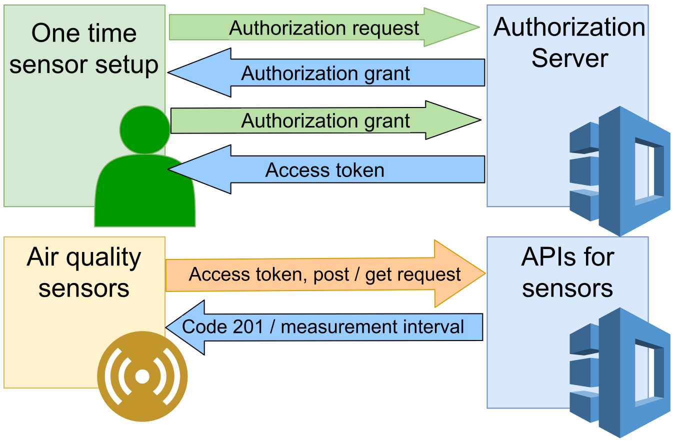


Fig. 1. Air quality sensor OAuth credentials flow

Lastly an API for the frontend will be created. Here the following features are required:

- Retrieve measured air quality level and location of each sensor
- Error handling in case of wrong request format
- Authorization and authentication checks for each request

With the previously explained APIs the backend system includes the necessary functionalities for all interactions for both the air quality sensors and the frontend.

## C. Creating the frontend application

With the air quality sensors and the backend in place this section will cover the consumable frontend application. This frontend should be accessible through a normal browser as well as a smartphone app. Hence the frontend will be implemented via a progressive web app to enable these two features. The homepage of this app will display a map of a certain region and show all the air quality sensor locations with their corresponding EAQI in it, see Figure 2.

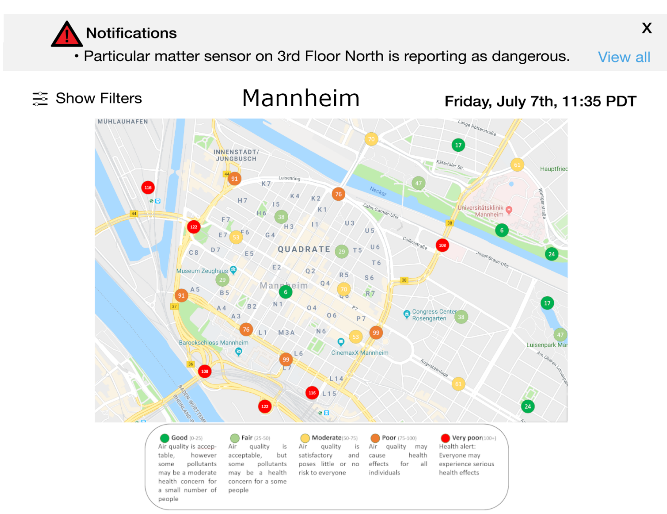


Fig. 2. Mockup of frontend homepage with Mannheim as displayed region

The user can interact with this map as he could in GoogleMaps and can also search for other regions. Moreover, each sensor can selected whereupon a popup will display the detailed current measurements of the selected sensor, see 3.

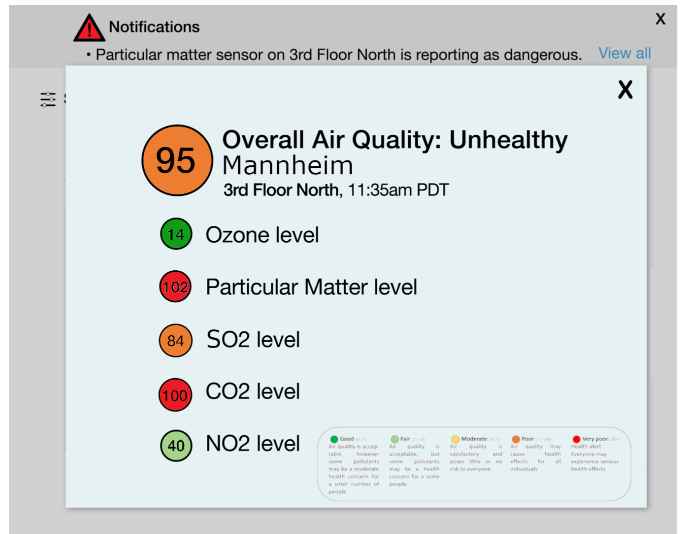


Fig. 3. DetailedSensorMeasurementsMockup

Notifications will be provided but no MockUp :¿

## VI. Conclusion

The implementation of an air quality information system in Perheim appears to be a reasonable concept. Through constant monitoring of various air pollutants, health risks can be reduced, environmental effects observed and laws enforced. By using inexpensive components and a simple archtitecture, costs are reduced and a first pilot implementation can be performed with comparitvely low effort. The first implementation serves as a foundation for a later extension with more sophisticated technology as well as integration to other smart home and city concepts.

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