enviroCar: A Citizen Science Platform for Analyzing and Mapping Crowd-Sourced Car Sensor Data

Arne Bröring[a], Albert Remke[a], Christoph Stasch[a], Christian Autermann[a], Matthes Rieke[a], Jakob Möllers[b]

[a] *52° North Initiative for Geospatial Open Source Software, Münster, Germany*
[b] *Institute for Geoinformatics, Westfälische Wilhelms-Universität, Münster, Germany*

Abstract

This article presents the *enviroCar* platform for collecting geographic data acquired from automobile sensors and openly providing those data for further processing and analysis. By plugging a low-cost *On-Board Diagnostics* (OBD-II) adapter into a car and using an Android smartphone, various kinds of sensor data measured by today's cars can be collected and uploaded to the Web. Once available on the Web, these data can be used to monitor traffic and related environmental parameters. We analyze the OBD-II interface and its potential usage for environmental monitoring, e.g., to estimate fuel consumption, resulting CO_2 emissions, as well as noise emission and standing times. Next, we present the main contribution of this paper, the system design of the enviroCar platform. This system design consists of the enviroCar app and the enviroCar server, which allows for flexible geoprocessing of the uploaded data. We focus in this paper on the description of the spatiotemporal RESTful Web Service interface and underlying data model specifically designed for handling the mobile sensor data. Finally, we present application scenarios in which the enviroCar platform can act as a powerful tool, e.g., regarding traffic monitoring and smarter cities (e.g., the detection of pollutant emission hotspots in the city), or towards applications for a quantified self (e.g., monitoring fuel consumption). We started the enviroCar project in 2013 and have been able to attract a growing number of participants since then. In a crowd-funding initiative, enviroCar was successfully funded by volunteers, demonstrating the interest in this platform.

1. Introduction

In January 2013, over 43 million cars have been registered in Germany [1]. This means, around one car per two inhabitants has been registered and similar

Email addresses: `a.broering@52north.org` (Arne Bröring), `a.remke@52north.org` (Albert Remke), `c.stasch@52north.org` (Christoph Stasch), `c.autermann@52north.org` (Christian Autermann), `m.rieke@52north.org` (Matthes Rieke), `jakob.moellers@uni-muenster.de` (Jakob Möllers)

Preprint submitted to Elsevier *May 5, 2015*

situations can be found in other Western countries. This amount of traffic has tremendous impact on the environment. Authorities need information about traffic to make reasonable decisions, e.g., to employ the right traffic planning measures, to implement air quality policies, or for city and land-use planning.

The goal of this work is to turn today's vehicles without high investments into mobile sensor platforms and their drivers into citizen scientists [2]. Thereby, *citizen science* has been defined by the European 'Eye on Earth' initiative [3] as *organized research in which members of the public - who may or may not be trained in science - gather or analyze data*. While the contributed automobile sensor data can be seen as Volunteered Geographic Information (VGI) [4], the process of acquiring such data goes beyond the principles of VGI, since the citizen is aware of actively participating in science projects. The gathered data can feed environmental monitoring systems that provide current geographic information about the traffic and the environment. Analysis of such data can produce information about current pollutant emissions, noise, slow-moving traffic, or improper traffic light circuits.

The contribution of this work is the design of the *enviroCar* platform [1] that aims at extracting sensor data from vehicles and enabling analysis on the basis of those data. This paper presents the design of the enviroCar system and describes possible application scenarios. All data uploads are published as *open data* and we aim at establishing an open science community that encourages external scientists and stakeholders to contribute by addressing research questions related to the collected data.

On-board computers of modern cars generate data in large quantities in order to control the functioning of the car – particularly, the engine. EnviroCar aims at providing access to those measurements, collecting them on the Web, and providing them for subsequent analysis. It is important that the enabling technology is cheap to facilitate citizen participation. Thus, we base our approach on the so-called *On-Board-Diagnostics 2* (OBD-II) interface which is openly defined [5] and present in all cars today. A commonly available OBD-II Bluetooth adapter is utilized to read this data. Retailers offer such adapters from about 18 EUR to 150 EUR. Through the enviroCar App, we enable the user's smartphone to connect to the OBD-II Bluetooth adapter and to query raw data from the car's sensors. The data is stored on the phone and the user is able to regularly transmit the data in anonymized form via a mobile Internet connection to the enviroCar server. The data can be further analyzed by additional processing components. Resulting information is made available as maps. All raw data as well as maps are published as open data and various interest groups, such as scientists, public administration, or industry, are encouraged to further use the data.

The remainder of the paper is structured as follows. Section 2 describes the technical background of this work, and describes existing research and projects in the context of citizen science and automobile sensing. In Section 3, an analysis

[1] `http://www.envirocar.org/`

of using automobile sensors for environmental monitoring is presented. Section 4 details the design of the enviroCar system, with a particular focus on the developed spatiotemporal Web Service interface and underlying data model. Application scenarios of the enviroCar platform are described in Section 5 and Section 6 discusses the results of this work. Section 7 concludes the paper and provides a perspective on future work.

2. Background and Related Work

This section first introduces the concepts of citizen science as well as Volunteered Geographic Information and relates the envisioned enviroCar system to those research fields (Section 2.1). Next, Section 2.2 presents background knowledge concerning automobile sensing and communication protocols, the On-Board Diagnostics system (OBD-II) as well as the CAN-Bus system. Finally, Section 2.3 gives an overview on existing projects in the field of automobile sensing.

2.1. Citizen Science

In citizen science, the common citizen is enabled to observe a certain phenomenon or domain that is of special interest for science [4]. Popular examples of citizen science projects are the World Water Monitoring Challenge [2] or the Christmas Bird Count [6]. Thereby, the term “citizen science” is closely related to the term “Volunteered Geographic Information” (VGI) [4]. VGI is a special form of user generated content and illustrates the fact that citizens voluntarily create data for a certain domain of interest. Although such citizens do not necessarily have a special qualification, authorities and the general public can profit from the gathered data.

While some citizen science projects require special qualifications, the system developed in this work invites citizens to participate without requiring any special qualification. However, the equipment, a car with an OBD-II connector, a low-cost adapter, and an Android smartphone, are needed to participate. Then, based on the established enviroCar infrastructure, various citizen science projects can be conducted, each addressing a particular research question and the according analyses of the enviroCar data.

For citizen science projects, the incentives of users to participate strongly vary. Self-promotion and the personal satisfaction of a user to see his/her contributions on the Web usable for others are possible reasons for an active participation [7, 4]. Examples for successful citizen science projects are the noise level assessment in cities using smartphones [8], or the engagement of school children in collecting local weather data and their contribution to a common platform as part of the GLOBE project [3]. It is therefore assumed that the enviroCar system can reach a motivated target group which is willing to participate. However,

[2] http://www.worldwatermonitoringday.org/
[3] http://training.globe.gov

further research and a practical roll-out of the system are required to prove this assumption.

Besides user incentives, an important aspect for the success of citizen science projects are mechanisms for managing the quality, trust, and credibility of the contributed data. Such aspects have been a topic of research since several years, see e.g., [9], [10], [11]. Beneficial for the quality of data collected through the enviroCar approach is that existing automobile sensors are utilized whose quality is also required for the working of the car itself. Other than citizen science projects which rely on human made observations, enviroCar relies on reliable sensor equipments. Consequently, the data quality being provided by the automobile sensors is expected to be sufficient for many purposes.

2.2. Automobile Sensing and Communication Protocols

Figure 1: OBD-II Bluetooth Adapter that is used to connect the smartphone to the OBD-II system (Source: `http://www.drivedeck.de`).

The On-Board Diagnostics interface (OBD-II) standard [12] provides methods to query realtime sensor values from controllers and sensors of a vehicle, e.g., related to the engine and exhaust system, but also internal errors are logged by OBD-II. In the United States, an OBD-II interface is mandatory in all new gasoline powered vehicles since 1996 (diesel since 1997) [13]. The European Union requires the presence of such an interface since 2000 (diesel since 2003) [14].

OBD-II enables querying of sensor values and parameters via a combination of modes and parameter identification digits (PID) [15]. As an example, the `Mode PID` combination for querying the engine coolant temperature is `01 05`. Allowed PIDs are standardized and have to be implemented by all manufacturers as far as sensors are present in the vehicle. Some car manufacturers add additional parameters, however, the documentation of those parameters is not publicly available. In addition to that, those manufacturer-dependent PIDs are not standardized and can therefore not be used for a generic solution.

2.3. Existing Automobile Sensing Projects

Using cars as mobile sensor platforms has been done before in other application contexts. Haberlandt and Sester proposed a method to measure and estimate rainfall using moving cars [16]. In this project, sensors observing the activity of the cars windshield wipers were combined with location data from

GPS receivers to determine the amount of rain for the current position of the car. Logging the data from a network of cars to a central database enables the scientists to calculate rainfall estimations. As it is stated in the paper, the imprecision of the sensors and especially the movement of the cars themselves add significant uncertainty to the result of the estimation.

Another project that uses cars as sensor platforms is presented by Hull et al. [17]. They also utilize the OBD-II interface to extract sensor data from the car's internal systems. Using a central server for the collection and analysis of the data relates to the enviroCar system proposed here. However, Hull et al. focus on the technical realization of the system, whereas environmental questions or analysis methods are only covered marginally. Today's technological advancements on the mobile phone market allow us to fade out these technological details. The enviroCar hardware component builds on the widely used Android smartphone and affordable OBD-II adapters. This allows an easier access to a potentially very large user group. Hence, the enviroCar aims at fostering the dialog between citizens, scientists and planners and focuses on providing a unique source of information, which can be used to analyze and enhance concepts in the field of mobility and environment.

Besides the research projects described above, there are commercial software solutions emerging which make use of the OBD-II port to further connect users with their cars. The Android application *Torque* is the most popular example and is listed with 500k-1000k installations in the Google Play Store [4]. Torque is able to extract and display OBD-II data in realtime using graphs or clocks. In addition to that, the content of the car's error log can be read, or captured tracks can be analyzed. Further functions such as a display that visualizes the optimum shift point to the driver can be included, so the app can passively help to reduce fuel consumption and emissions. Other examples of similar software projects are *Automatic* [5], *Moj.io* [6], or *EcoHelper* [7]. These applications combine the data from internal car sensors (e.g., accelerator pedal) with the phones GPS sensor. The functionalities provided to the user vary, and range from locating the vehicle, calculating costs of driven trips, to checking the car's health. However, while those commercial software projects solely aim at providing personal benefits to the user, enviroCar focuses on making gathered automobile sensor data accessible and useful for the public.

3. Vehicular Sensor Data for Environmental Traffic Monitoring

This section analyzes how the data from today's cars, accessible through the OBD-II protocol, can be used for environmental traffic monitoring.

[4] `https://play.google.com/store`
[5] `http://www.automatic.com/`
[6] `http://www.moj.io/`
[7] `http://www.ecohelper.ch/`

3.1. Estimation of Current Fuel Consumption

The engine fuel rate sensor is only in rare car models readable, as it is not mandatory in the OBD-II standard protocol. An alternative to *estimate* the fuel consumption for the enviroCar system is the usage of the mass air flow (MAF) sensor, which measures the amount of air that is flowing into the engine. The engine control unit uses the MAF sensor to determine how much fuel has to be inserted into the cylinders. Thereby, the air-fuel-ratio (AFR) remains within a certain range to produce a combustible mixture. A combustion of gasoline is complete for a ratio of 14.7 kg of air per 1 kg of gasoline. The engine control unit, however, adjusts this ratio for better performance in certain states of the engine, e.g., when the engine just started. This causes differences between calculated and actual fuel consumption. Furthermore, the concept of utilizing the MAF sensor for fuel consumption does not work for diesel engines, since the air-fuel-ratio is not controlled by engine.

Having those considerations in mind, the following formular as described by [18] presents an estimator for *gasoline* consumption:

$$\frac{fuel\,weight}{s}\left(\frac{g}{s}\right) = \frac{MAF\left(\frac{g}{s}\right)}{AFR}$$

3.2. Estimation of CO_2 Emission

Although CO_2 is not directly harmful to human health, it is a very important component of exhaust gases because of its influence on the atmosphere and climate change [19]. In contrast to other pollutants, CO_2 emissions are not influenced by filters or catalysts, which makes its estimation easier [20]. CO_2 emissions are in a linear relationship with the fuel mass that is combusted in the engine. Therefore, we can derive CO_2 emissions when the current fuel consumption is known. In case of gasoline, combusting 1 liter results in 2.35 kg of CO_2. In combination with the formula from Section 3.1, we can estimate CO_2 emissions in $\frac{kg}{s}$ by utilizing the following formular:

$$CO_{2\,Gasoline} = ((MAF/14.7)/745) * 2.35$$

3.3. Estimation of Noise Emission

Noise emission estimation is not straightforward, since many parameters such as road and tire quality, or aerodynamic drag influence noise emission from vehicles [21]. Nonetheless, we can use OBD-II sensors to support the estimation of local noise emission by measuring the engine speed (in revolutions per minute). Higher engine speed correlates to higher noise emission [21]. In addition to that, higher vehicle speeds lead to more noise, which is emitted by the tires [22].

We therefore capture engine speeds using OBD-II and detect areas where engine speed is increased significantly in comparison to all measured engine speeds. In combination with speed information, we can contribute to estimating noise emission on a larger scale with a higher confidence.

3.4. Estimation of Standing Time and Slow-moving Traffic

The enviroCar system can contribute to the estimation of standing times and slow-moving traffic by using information from the vehicle speed sensor available in the OBD-II protocol. Once this data is collected on the enviroCar server it can be further (geo-)processed. By calculating kernel density estimations [23], areas with higher occurrences of measurements with 0 $\frac{km}{h}$ are shown on a map. This can, for example, indicate inefficient traffic light circuits that hamper traffic flow.

The same method can be applied to detect slow-moving traffic. If the measured speeds differ significantly from the speed limit at a certain location, it is likely that the traffic flow is reduced. In order to perform this analysis, we extract speed limit data from OpenStreetMap [8] and compare to the measured values.

4. System Design

This section presents the design of the developed enviroCar system. Details on the enviroCar app are presented in Section 4.1, the server-side components are explained in Section 4.2, and the designed server interface is described in Section 4.3.

An overview of the system design is presented in Figure 2. The enviroCar app runs on the Android smartphone of the user and is connected to the OBD-II bluetooth adapter to read and collect the automobile sensor data. The enviroCar app uploads collected data to the enviroCar server. Here, the data is made publicly accessible and can also be further processed through the enviroCar processing components. Finally, information products are created based on the data which are visualized in mapping applications.

4.1. enviroCar App

Before the app can work, the user has to configure settings about his/her car (e.g., manufacturer and type). Next, after starting the measurement process, the application (Figure 3) automatically connects to the Bluetooth adapter (see e.g. Figure 1) and queries sensor data. This is done by a so-called *Service* of the Android operating system which runs autonomously in the background of the smartphone. In order to connect the OBD-II Bluetooth adapter and smartphone, the standardized Bluetooth connection process is followed. The devices can be connected via the common coupling mechanism provided by the Android smartphone which can be found in the settings.

Once data are captured, the user can upload recorded tracks to the enviroCar Web server. Before uploading, the tracks are anonymized, by removing all user related data and cutting of the first and last 200 m of the track. Through this mechanism, the uploaded tracks cannot be traced back to a geographic origin or

[8] `http://www.openstreetmap.org`

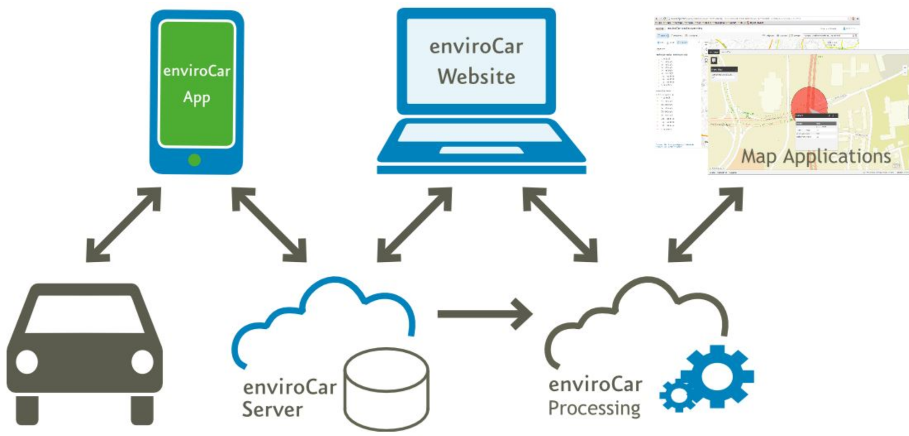

Figure 2: Overview of enviroCar system design.

destination. Each measurement is stored temporarily on the smartphone. Via the mobile Internet connection, measurements are uploaded to the Web server using HTTP POST.

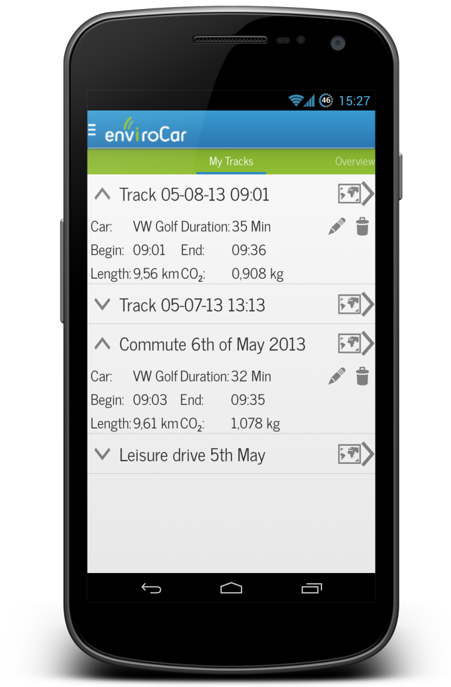

Figure 3: The enviroCar application showing an overview of recorded tracks.

Car manufacturers are using different internal protocols to support the OBD-II standard (Section 2.2). Hence, for being able to generically extracting automobile sensor data, an OBD-II Bluetooth adapter device has to be chosen that supports all protocols and selects the correct protocol automatically, so that this problem does not have to be addressed by the smartphone application. For testing and evaluating of this work, the ELM 327 OBD-II Bluetooth adapter [24] with an auto detect function is used.

As described in Section 2.2, the OBD-II interface can be queried by sending a mode and PID combination, which identifies a certain sensor parameter. The returned value is raw data without a meaningful unit or metadata. Standardized formulas have to be applied to each returned value to turn the raw data into human readable measurements.

Accurate location information is crucial for every single measurement, since vehicles are typically changing their position continuously. The phone's GPS sensor provides us with an accuracy of 15 m or less in 95% of all cases [25]. However, GPS position accuracy can become worse in dense urban canyons. This problem is recognized, but its solution is out of scope of this work, since for the enviroCar App, we can only rely on the phone's internal GPS.

4.2. enviroCar Server-side Components

Once the data captured by the enviroCar App are uploaded to the enviroCar Server, they can be further processed and provided to the public (in case the user agrees to this). Therefore, the measurements are stored by the enviroCar Server in a NoSQL database (i.e., MongoDB [9]) to address the potentially high performance and scalability demands once the community is building up. Via a clearly defined API of RESTful Web Services (Section 4.3.2), the raw and processed data are easily accessible. The data is offered via common data formats that are easy to process: the JSON format is particularly well-suited for Web applications, the CSV format allows the direct processing with statistical tools, and the Shape-file format supports the analysis and visualization of the data in GIS.

The collected data is further analyzed using processes implemented as OGC Web Processing Services (WPS) [26] as shown in Figure 4. Through this interface the processes can be integrated into GIS- as well as Web application environments. The publication of an analytical process via the WPS interface has been proven to be beneficial for its collaborative development. The source code of the process implementation as well as the WPS framework are published as open source software[10].

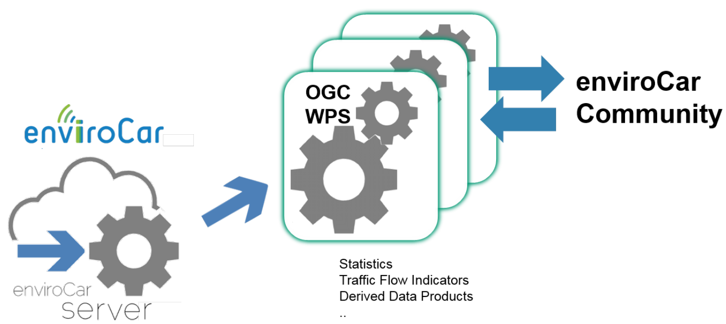

Figure 4: Illustration of the usage of Web Processing Services in enviroCar.

The results of data analyses are visualized as maps and accessible through an interactive user interface as well as through Web Service interfaces. Figure 5 and 6 show two such maps. Figure 5 shows an overview map of measured tracks in which the color coding represents the captured velocity. The map shows raw data which are however aggregated according to the zoom level. Figure 6 shows a density map that allows to interpret which parts of the road network have a significant accumulation of high CO2 values.

[9] `http://www.mongodb.org/`
[10] https://github.com/enviroCar

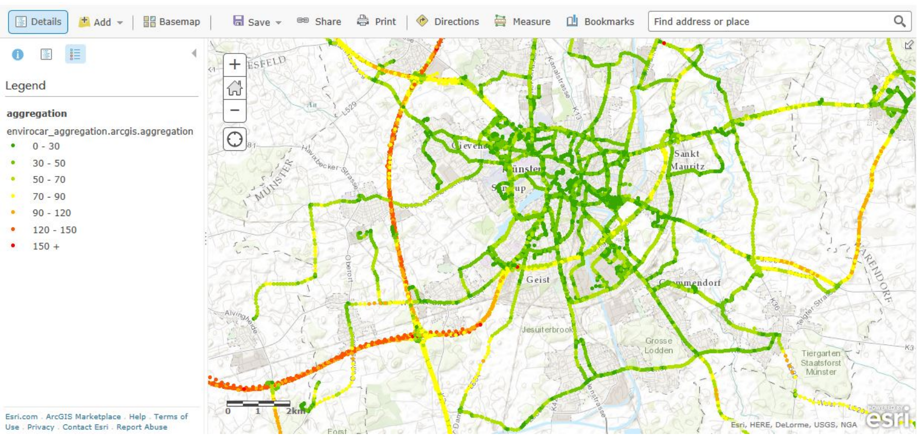

Figure 5: Screenshot of enviroCar overview map.

4.3. enviroCar Web Server Interface

In the following, we present the data model to represent enviroCar data and the designed RESTful Web Service interface to make the gathered data available via the enviroCar server[11].

4.3.1. Data Model and Supported Formats

Figure 7 shows the concepts contained in the data model and the relationships between them, including cardinalities. The model is inspired by the Observations & Measurements (O&M) standard [27, 28] of the Sensor Web Enablement initiative [29] at the Open Geospatial Consortium (OGC). At the center of the model is the *Measurement*. This concept comprises multiple properties, such as the ID, the location where the measurement was taken, as well as the time stamp when it was taken. Further, it comprises multiple *Phenomena*. The phenomenon concept comprises the value captured by the sensor and the associated unit. The *Sensor* concept itself is linked by the measurement. Also, the user who owns the sensor is associated with the measurement. Users may be organized in *Groups* and may conduct certain *Activities*. Measurements may belong to a *Track*. In case of enviroCar, this is always the case, but the data model could also be utilized in other applications for handling user generated measurement data. In such scenarios, measurements do not need to be part of a track.

To flexibly support different use cases and applications, the enviroCar Server is capable of encoding the data in different formats. The default format is JSON, but also an RDF encoding is supported for all data concepts. In case of the tracks concept, the enviroCar Server is additionally capable of encoding

[11] A detailed description of this server interface can here: `http://envirocar.github.io/enviroCar-server/`.

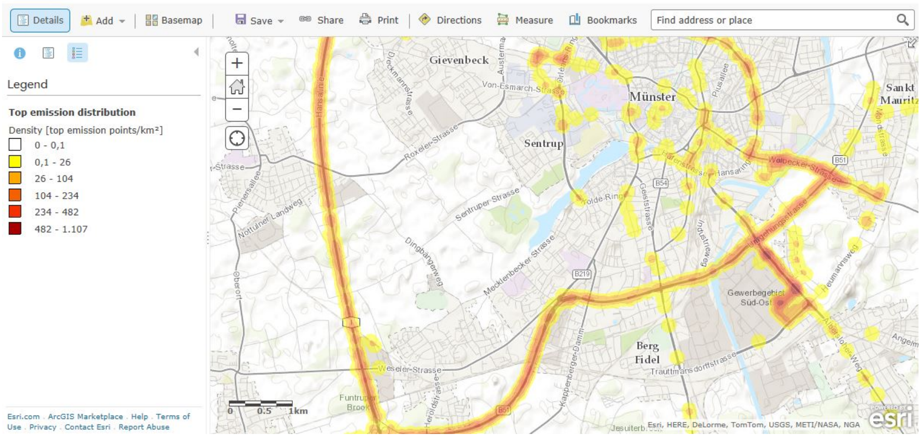

Figure 6: Screenshot of a density map for measured CO2 values.

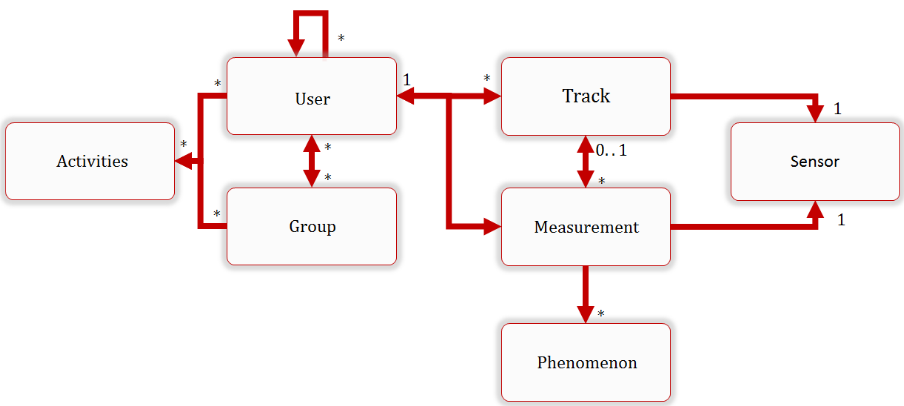

Figure 7: Designed data model to represent enviroCar data.

the data as an Esri's Shape File or in the CSV format. Listing 1 shows an example JSON instance of a measurement. The above described data model is instantiated and the measurement possesses the described properties and realtions to other concepts.

Listing 1: JSON encoding of a Measurement.

```
{
  "type": "Feature",
  "geometry": {
    "type": "Point",
    "coordinates": [ 7.6169, 51.9496 ]
  },
  "properties": {
    "id": "51c97d05e4b0fe5a04e9e76d",
    "time": "2013-06-08T11:31:11Z",
    "sensor": {
      "type": "car",
      "properties": {
```

```
        "id": "51c96afce4b0fd063432096f",
        "model": "R 1200 GS ADV",
        "fuelType": "gasoline",
        "manufacturer": "BMW",
        "constructionYear": 2012
      }
    },
    "track": "51c97d05e4b0fe5a04e9e733",
    "phenomenons": {
      "Consumption": {
        "value": 0.0007811290513528035,
        "unit": "l/s"
      },
      "CO2": {
        "value": 3.65,
        "unit": "g/s"
      }
    }
  }
}
```


4.3.2. RESTful Web Service Interface

The enviroCar RESTful Web Service interface defines how to access the data available through the enviroCar Server. Instead of providing the data in the classic way of SOAP/WSDL based Web Services [30], as it is for example done by OGC's Sensor Observation Service [31] for O&M encoded XML data, the enviroCar Server follows the RESTful [32] approach. The enviroCar RESTful Web Service interface makes instances of the data concepts described in Section 4.3.1 available as individual resources that are identified in HTTP requests using URLs. For this purpose we have defined URL patterns for the different resources. Listing 2 and 3 show as examples the defined URL patterns for the *Sensors* and *Measurements* resources.

A running example of the enviroCar RESTful Web Service can be accessed here: `https://envirocar.org/api/stable`. Following the definition of Listing 2, the collection resource of all registered sensors of the enviroCar Server can be accessed through this URL: `https://envirocar.org/api/stable/sensors`. To access a concrete sensor resource, its ID needs to be appended to the collection resource URL, for example: `https://envirocar.org/api/stable/sensors/51c96afce4b0fd063432096f`. As defined in Listing 3, also here a collection of all measurements as well as individual measurement resources can be accessed (e.g., `https://envirocar.org/api/stable/measurements/51c97d05e4b0fe5a04e9e76d`). Further on, measurements can be queried as a sub-resource of the *Tracks* as well as the *Users* resource. Also, tracks can be queried as a sub-resource of users.

Extending these resource identifying URL patterns, which are resolvable through HTTP GET calls, we have enabled the geospatial filtering of measurements and tracks. Such geospatial filtering can be specified through a simple bounding box appended as a query parameter to the URL of the resource collection. The coordinates of the bounding box are specified in the WGS84 reference system and are given in the order: minX, minY, maxX, maxY. For example: `https://envirocar.org/api/stable/measurements?bbox=7.0,51.1,7.3,52.0`.

Since resource collections can be huge (e.g., all measurements hosted by the server), enviroCar's RESTful Web Service Interface supports pagination. I.e., every collection resource offers two query parameters: `limit` and `page`. While `limit` specifies the amount of retrieved entities, `page` indicates the position in the set of all entities. To protect the server performance, it is not possible to retrieve more than 100 entities at once. To allow navigation through the result set the service supports link headers [33].

Apart from querying resources via HTTP GET from the enviroCar Server, the RESTful Web Service interface also allows to create new resources using the HTTP POST method and to delete resources using HTTP DELETE. To protect the underlying enviroCar data, those methods are only accessible after successful user authentication and if required access rights are granted.

Listing 2: URL pattern for accessing *Sensors* resource.

```
/sensors
/sensors/:sensorID
```

Listing 3: URL pattern for accessing *Measurements* resource.

```
/measurements
/measurements/:measurementID

/tracks/:trackid/measurements
/tracks/:trackid/measurements/:measurementID

/users/:username/measurements
/users/:username/measurements/:measurementID

/users/:username/tracks/:trackid/measurements
/users/:username/tracks/:trackid/measurements/:measurementID
```

5. Application Scenarios

In the following, we present current works which utilize the enviroCar citizen science platform and the data gathered from it for different purposes.

5.1. Identifying Local Characteristics of Environmental Emissions

Making use of the techniques discussed in Section 3, an important outcome of the enviroCar platform is the collection of data to learn about the environmental impact of cars through their emissions, such as CO2 or noise. In particular, current research in context of enviroCar focuses on the development of methodologies to assess CO2 emission profiles of certain sections of a traffic network. Aim is to identify in a first step those traffic sections, which stand out with high CO2 emission values. For identified traffic sections, further investigations can be triggered to find reasons for the higher emissions and eventually find means of traffic steering to alleviate the problem.

5.2. Generating Data for Traffic Planning

In the context of traffic monitoring, the enviroCar platform offers the opportunity to collect a larger, indiviualized sample of vehicle data. Thereby, an important question in this context is how many tracks are required to allow for significant statements regarding a particular matter. Further, methods are being researched that allow the observation of change impact within a traffic infrastructure regarding, e.g., the impact of traffic light circuit adjustments on pollutant emissions.

Figure 8 shows a screenshot of an application prototype that is able to extract descriptive statistics about the traffic flow at selected traffic nodes. Stops are defined as sequences of at least three successive measurements with speed values lower than 5 km/h. Based on those measurements, the number of stops/pass-throughs within a buffer around a selected traffic node, e.g., a crossing with traffic lights, are determined. The buffer around the node is marked by the red circle around the node in the map. The number of stops and passages is shown in a pop up window. The analytical process to calculate this is implemented using a Java library and is embedded into enviroCar's WPS infrastructure.

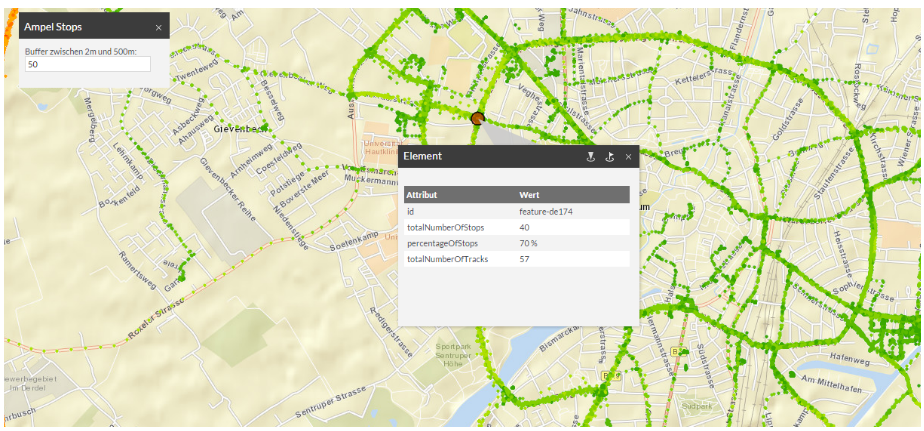

Figure 8: Screenshot of a map application for traffic planning, which determines number of stops at traffic nodes.

5.3. Contributing to a Quantified Self

The term 'quantified self' [34] stands for the interest of many people to learn more about themselves. A plethora of mobile sensors and apps can already be used to gain a comprehensive picture of oneself and ones habits. Those insights can be used to change habits, and to improve health and quality of living.

The enviroCar platform enables the collection of data about the personal mobility behaviour: The user receives information about driven routes, velocities, and fuel consumption. Hence, the user can answer questions such as 'how long takes my way to work on average?' or 'how much fuel/costs do I save if I go to my fitness studio by bicycle instead of taking the car?'. On the other hand, the user can compare his/her measured values with the averaged values of other contributing users, e.g., comparing average speed or fuel consumption. In addition to this, it can be determined how the driving style influences CO2 emission, which encourages to optimize towards a more eco-friendly the driving style.

6. Discussion

The key advantage of the enviroCar system is the potentially very high number of contributing cars and the resulting live monitoring of traffic conditions and emissions through continuous data streams. Nevertheless, the crucial aspect of the approach is the attractiveness to participate. To achieve the goal of creating a live traffic monitoring system, incentives for user participation need to be high. As part of the enviroCar project [35], we conducted a crowd-funding campaign[12] to advertise the enviroCar concept and to start the community building. This crowd-funding campaign was successful in acquiring a 10.000 EUR budget within 60 days funding from volunteers and interested organizations. This demonstrated the interest in the enviroCar approach. Today, we have over 500.000 measurement data points collected and we can see continuing growth of the data basis. However, despite these first successes, a wide-spread user community is still missing.

The methods described in Section 3 for estimating environmental parameters through OBD-II and their application as described in Section 5 are promising. However, there are still challenges remaining for successfully utilizing the OBD-II interface for environmental traffic monitoring. Most significantly is the incompatibility of certain vehicle types with the OBD-II standard. Consequently, the availability of particular sensors varies between vehicles. Further, the inability of estimating fuel consumption for diesel engines is a recognized shortcoming. In addition, some vehicle types do not support the MAF sensor, although it is mandatory in the OBD-II standard. Then, the MAF has to be estimated first by utilizing other parameters, which are readable, namely temperature, air pressure, and engine speed. An according formular is presented in the patent [36].

A challenge concerning the noise estimation (Section 3) is that only trends and relative emission values can be calculated. Absolute measurement values in units such as decibel cannot be provided with this method. Also, noise emissions are influenced by many additional parameters [21] so that it is impossible to develop a generic and exact solution at the same time. Nonetheless, an approach that uses confidence intervals to identify measurements according to their statistical significance can give an indication to noise emission by vehicles. These local noise estimates can support noise assessment within a region.

[12] `http://www.indiegogo.com/projects/envirocar`

7. Conclusions and Future Work

The key contribution of this paper is the design of the enviroCar system, consisting of (1) the design of a RESTful Web Service interface and a data model to give access to the mobile sensors data through spatiotemporal filtering, (2) the enviroCar server to store and distribute collected data, and (3) an Android application that is capable of reading automobile sensor data.

Lessons learned from this work, have been discussed in Section 6. Primarily, this work presents an infrastructure which enables the conduction of novel citizen science projects for exploiting automobile sensor data to support environmental and traffic monitoring. The utilization of smartphones to read automobile sensor data is a powerful combination that offers many new possibilities for geographic information science. The enviroCar prototype has demonstrated how such a system can be designed and implemented.

The next step on our research agenda builds up on the here described achievements. An essential aim for future work is to continue to improve the attractiveness of participating in such a platform. This includes research on general incentives, business models, as well as usability of the smartphone application and the enviroCar website. In addition, new interaction tools between citizens, scientists, and experts from public adminstrations and companies will be created to foster the dialog and collaboration. Further, we will concentrate our research on the development of improved approaches for the estimation of environmental properties such as CO2 emission and noise pollution caused by cars. Thereby, an important aspect will be to consider and handle data quality and uncertainty aspects within the data contributions from citizens.

Acknowledgements

This work has been financially supported by the project *Flexible and Efficient Integration of Sensors and Sensor Web Services* funded by the ERDF program for NRW (contract number N 114/2008), as well as the *52° North Initiative for Geospatial Open Source Software*. Many thanks go to the enviroCar project team [35] and their enthusiastic work on implementing the here presented approach. Finally, we thank all the sponsors of the enviroCar crowd-funding initiative [37] for supporting us in building this new source of environmental data.

References

enviroCar