Wearable Gas Sensor Node for Large-Scale Environmental Monitoring

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Abstract

Low-power consuming, small, selective gas sensors may be used to build wireless, wearable device for large-scale deployment of chemical sensing technologies. In this contribution a battery-powered, Bluetooth Low Energy (BLE) sensor node for the monitoring one of the most important air pollutants is presented. The device can connect to any smart device and uses its geolocalisation capabilities to provide time-and-spatially resolved data of pollutants. The data is displayed on a live map to visulize the air quality in real time.

Introduction

Mono-nitrogen oxides (NO_x) and particle matter (PM) are responsible for a number of adverse health effects [1]. Among other things NO_x are associated with the formation of smog and ozone, a reason for acid rain [2-4]. Even at low concentration levels both NO and NO_2 may cause harmful effects on the human metabolism, which is especially relevant given the considerable background levels in urban conglomerates. Oftentimes these levels are already close to hazardous levels [5] and high-resolution data are required to identify hotspots and peak events. While in the past highly sensitive systems have been deployed [6,7], large-scale deployment and continuous monitoring is still not feasible at reasonable cost.

By combining Machine-To-Machine techniques with small-sized, low-cost, low-power consuming sensing devices it is possible to overcome the current impasse and provide continuous monitoring using citizen science approaches. To this end, the battery-operated sensing hardware presented herein, is equipped with a BLE module making it an add-on device that can be connected to any smart device. The latter provides necessary additional services, crucially including internet connectivity, geo-localization, and a time stamp for data synchronization.

The State of the Art in measurement of NOx, given the comparably low concentrations of these gases, relies either on bulky and expensive stationary measurement stations [7] or on technologies that require collection and individual analysis of samples such as passive chemical sensors [8]. Other studies have created networks of internet-connected sensors [9,10,11], both stationary and dynamic; but the resolution of commercially available sensors compatible in size, cost and power requirements with IoT requirements is not high enough to properly measure the levels that are typically found in cities [9,10]. This implies that current sensor technologies should be improved to increase the resolution of these systems.

System Concept

Combining wearables with smart devices enables establishing easily adaptable, mobile sensor networks that may be used to gather environmental data on a large scale. The current version of the device is powered by a battery, and a PSoC6® microcontroller manages communication as well as data collection from sensors providing information on temperature, humidity, pressure, NO_2 concentration. To improve the signal-to-noise ratio the microcontroller performs averaging and sends the data to a dedicated smart-device app every 30 s. This introduces a position uncertainty into the data depending on the moving speed of the wearable carrier. An overview of the mobile sensor node concept is depicted in Figure 1.

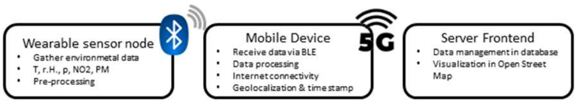

Figure 1: Schematic depiction of the system's components.

In order to measure the NO_2 concentration, the system uses an electrochemical cell (SPEC Sensors 3SP_NO2_5F), with a resolution that the datasheets states is 20 ppb NO_2, which is then digitized using the integrated Analog-to-Digital Converter (ADC) of the PSoC6 microcontroller. The SPEC NO2 sensor outputs a DC current directly proportional to the concentration of NO_2 in the ambient, and includes a filter for O3 in order to prevent cross-sensitivity, which adds to the temporal response function of the sensor system. The response time of the sensor to changes in the concentration of NO_2 is of 15s, so the spatial resolution will be limited by this value in conjunction with the speed of the vehicle in which it is installed. In the system, the current signal is amplified and converted to a voltage signal using a transimpedance amplifier, whose output can be read by the ADC. The temperature and air pressure compensations are carried out by software using the data from the Bosch BME280 temperature, pressure and humidity sensor. The low power consumption of all of

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the elements and the BLE protocol make a very long battery life possible. The device can be seen on Figure 2. Since the start-up time of the electrochemical sensor is on the excess of 1 h and the power consumption very reduced, the sensor is intended to be powered for extended amounts of time. Application examples are equipping fleets of public transport vehicles such as buses or taxis with these sensors, connected either directly to the vehicle battery or, for easier retrofitting to existing vehicles, with their own battery and solar power. Once the data has been obtained and stored into a server, a variety of mathematical models can be applied to extrapolate from the discrete position, time and concentration values to digital maps of the concentration over time [12,13].

Figure 2: Picture of the described device, which was used in the measurements shown in Figure 3.

Results

To showcase the capabilities of the approach, a total of 8 devices have been fabricated and calibrated in the laboratory. The calibration results show that the repeatability of NO_2 sensors in terms of sensitivity towards NO_2 is not sufficient for deployment withouth performing reference measurements first. Furthermore, that limit of detection has not been replicated in all instances and drift of the sensitivity over time limit the long time stability and makes continuous calibration necessary. Consequently, the use of electrochemical gas sensors for this application requires considerable calibration costs, which offsets the low purchase price.

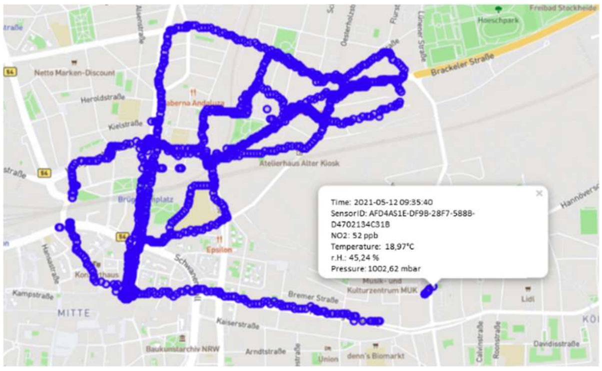

Figure 3: Data fusion may be used to create high resolution live maps of air pollution of more advanced analysis.

Nonetheless, the possibilities of combining data from numerous sensor nodes to create a pollution map are shown in Figure 3, in which data from a walkabout in Dortmund's city centre on 5 May 2020 can be seen. The map is created automatically and in real time using the data sent to the server.

Literature

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