Environmental Wellbeing through Guerilla Sensing

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Abstract: All over the world, individuals, companies, and institutions are exploiting the environment to gain an advantage for themselves. The damage to the environment affects people's health and environmental wellbeeing. By Guerilla Sensing, we provide a platform to detect, spotlight, and monitor environmental pollution, that allows citizen to trigger a closed control loop and react to this exploitation by providing data reflecting the current environmental situation. It consists of an adaptive network of low-cost sensor nodes connected to an extensible platform, enabling complex analyses and detailed notifications. Guerilla Sensing can be used by citizens without any deep knowledge in measurements or computer science.
The paper introduces the approach and the components of this platform. Applied to environmental parameters such as radiation and particulate matter, Guerilla Sensing is exemplarily evaluated.

Keywords: Citizen Science; Guerilla Sensing; IoT; Sensor Nodes; EIS; Sensor Network

1 Motivation

Today's society is facing huge environmental and health problems due to accumulated pollution since the beginning of the industrial era [Br03]. People, companies, and governments seek wealth or profit, but they often compromise on environmental sustainability. State institutions formulate threshold values for pollutants and enforce their compliance to protect their citizen. But sometimes, these institutions, are either missing the technical equipment to detect threshold value violations or they are not willing to do so in order to avoid conflicts of interests. Citizens are often unsettled, frustrated, or suspicious because they do not trust in public measurements: measurements are carried out too infrequently, with unsuitable means or at the wrong locations.

Companies report their efforts to improve their environmental performance in sustainability reports [Is01; SN18]. Comprehensible and verifiable sustainability reports serve to optimize the companys' ecological reputation. For an increasing amount of customers this is an important buying criterion [BR00]. A verification of statements on environmental parameters by the public, the economy, the agriculture, etc. is often impossible for citizens and requires comprehensive knowledge of measurement methods and measurement technology. Thus, an easy to use and cost efficient means to measure, monitor, and analyze environmental data is dearly needed. Citizens without detailed technical knowledge must be enabled to flexibly adapt simple measurement devices to a variety of different environmental phenomena.

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In summary, citizens and citizen scientists demand a low-cost and easy to use way to monitor and log their surrounding environmental situation, to spotlight and report environment influences, as well as to observe the effects as the consequences of their reports, or to increase transparency, or even for more complex research purposes.

This paper is organized as follows: After introducing existing works on citizen science-oriented acquisition and analyses of environmental data in Section 2 the approach of *Guerilla Sensing* is presented in Section 3. Section 4 exemplifies the realization of this approach, and Section 5 outlines a set of scenarios the *Guerilla Sensing* approach is applied to. Finally, Section 6 draws a conclusion.

2 Related Work

The direct surrounding environmental situation of citizens can be described by several parameters. These parameters include, e.g. the carbon dioxide concentration, radioactive pollution, and fine dust. The particular environmental parameters at a point in time can be quantitatively determined by measurements. Thus, individually measured values can be compared with each other or to reference values. Accordingly, the environmental situation, citizens are confronted with, can be classified by measuring and comparison. If there is a hypothesis of a harmed environmental condition, the characteristics of environmental parameters concerned can be measured and compared against specified reference values. Depending on this result of the comparison, the hypothesis is confirmed or refuted.

The environmental parameters fluctuate over time. Individual measurements may also exhibit various types of error. Often, several measurements taken over time are needed to come to a well-founded statement. Repeated manual measurements are time-consuming. With an autonomous solution for measuring environmental parameters, as in the citizen science projects *luftdaten.info* [Lu21] and *senseBox* [GI21b], the time required can be reduced and measurements can be performed consistently.

***luftdaten.info*:** With *luftdaten.info*, the *OK Lab Stuttgart* provides a platform for the collection and analysis of fine dust measurements. Interested citizens can participate in the collection of fine dust measurements by building and / or operating a sensor node. On the website of *luftdaten.info*, the construction of a sensor node is described by a construction manual. Additionaly, a firmware for the sensor node is offered for download. Once put into operation, sensor nodes measure the fine dust load of the surrounding air and send the values measured to *luftdaten.info*. Currently, measured values are visualized on a map. On another map, showing the individual sensor nodes, logged-in users can register for notifications of fine dust limit violations. In addition to fine dust, *luftdaten.info* also measures temperature, relative humidity, pressure, and noise. The active, country-specific offshoots of *luftdaten.info* called *influencair.be*[2], *airbg.info*[3], and *luftdata.se*[4] demonstrate the transferability and applicability of this citizen-centered idea.

The assembly instructions and the firmware for the sensor node make it possible for every citizen to participate in the data collection of *luftdaten.info*. Moreover, a sensor node of *luftdaten.info* is composed of freely-available and low-cost components. When citizens distrust the collected data, or wish to have the data collected at other times or at a different location, then they can perform measurements by themselves. With the help of the maps provided on the website, citizens can actively inform themselves about the current environmental situation or register for self-selected fine dust limit violations. This gives citizens another source of information besides the authorities to assess their own environmental situation. The *OK Lab Stuttgart* focuses on air data and / or noise data with *luftdaten.info*. Thus, *luftdaten.info*, in particular, covers environmental parameters influenced by traffic. In order to detect a variety of pollution types, a wider range of environmental parameters needs to be monitored. The *senseBox* approach from *GI@SchoolLab* has a flexible design and can be equipped with many different sensors so that a wide range of environmental parameters can be recorded.

senseBox**:** In 2010, the student and research laboratory *GI@SchoolLab* at the Westphalian Wilhelms University of Münster in Germany developed *senseBox* [GI21b]. With *senseBox*, the *GI@SchoolLab* primarily aims at supporting teachers in educating students in the collection and analysis of environmental data. In addition, *senseBox* is suitable for citizen science projects and environmental data collection. The core of a *senseBox* is a microcontroller called *senseBox MCU*. It can be complemented by a wide range of communication modules and sensors offered on the *senseBox* website. A *senseBox* can be equipped with scenario-specific hardware modules and can be freely programmed with the graphical programming language *Blockly*. In addition, a website also offers teaching materials and documentation. Different environmental parameters can be measured and published on the *openSenseMap* [GI21a] platform, where each registered *senseBox* is displayed on an map.

The flexible design of the *senseBox* and the free programming feature using *Blockly* allows many possible applications. Communication modules and sensors can be selected specifically for each scenario. This can potentially detect many types of pollution at different locations, based on different preconditions. Like *luftdaten.info*, *GI@SchoolLab* offers with *openSenseMap*, a map on which citizens can actively inform themselves about the current environmental situation. However, technical knowledge is required to program a *senseBox*. Furthermore, the hardware components of a *senseBox* are more expensive compared to other freely available ones on the market. In order to offer as many citizens as possible the possibility to record and classify their environmental situation, the required technical knowledge and the costs for the hardware components must be as low as possible.

[2] `https://influencair.be/`
[3] `https://airbg.info/`
[4] `https://luftdata.se/`

Especially, if there is a conflict of interest with authorities or polluters due to particular measurements, then these measurements cannot be performed undisturbed without further arrangements. Following the movement *Guerilla Gardening* [Mü11], in which participants act covertly to protest land scarcity, measurements can also be performed covertly. If the conflicting party does not know that a measurement is being made, then that party cannot disrupt or influence the measurement. But neither *luftdaten.info* nor *senseBox*, respectively *openSenseMap*, actively support covert measurements.

Even if measurements can be performed and published undisturbed, this does not lead to a stop of the observed pollution. Politics and authorities must be involved so that polluters can be fully identified and their undertakings be stopped. By the *Guerilla Sensing* approach, the ideas behind *luftdaten.info*, *senseBox* and *Guerilla Gardening* are combined, complemented, and extended to an overall concept to ensure the environmental wellbeing of citizens.

3 The Guerilla Sensing Approach

The *Guerilla Sensing* approach is based on a closed control loop (cf. Fig. 1) that aims at stopping environmental pollution. As indicated, a polluter has a harmful impact on the

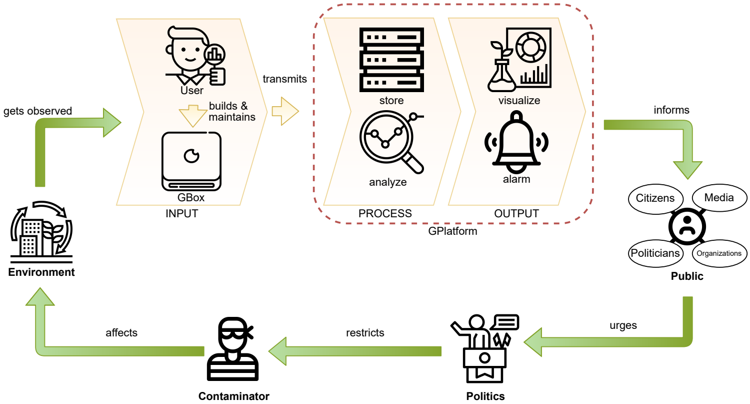

Fig. 1: The control loop behind *Guerilla Sensing*, taken from *Guerilla Sensing* [Bl21].

environment. Citizens who suspect environmental pollution would like to investigate and confirm or refute their suspicions. To do this, citizens can assemble and operate a sensor node, called *GBox*, scenario-specific from freely available and low-cost components to detect their environmental situation. The instructions needed to build a sensor node are provided on a website along with coresponding firmware. Thus, even citizens with no prior technical knowledge can build and operate an *GBox* on a small budget. If citizens are distrustful of the measurement data, they can perform their own measurements at any time.

Once in operation, a *GBox* autonomously monitors environmental parameters. The collected measurement data is sent from a *GBox* to the *GPlatform*. On the *GPlatform*, the data is stored, processed, and published on a map, the latter possibly with an adjustable delay. By publishing the measurements, citizens can be informed about the environmental situation. With the adjustable delay of publication, measurements can be covertly taken over some period of time. Polluters have no chance to detect covered measurements via the *GPlatform*.

In case of over- or undershooting of reference values, previously registered citizens and institutions are notified immediately. Even without an active search, citizens and institutions can get informed about environmental pollution. As soon as the collected measurement data confirms a suspicion of environmental pollution, citizens and institutions can use the measurement data to motivate politics and authorities to take action. Politics and authorities are expected to follow up on the suspicion and, if pollution is present, to fully identify the polluters and stop their activities. Whether a polluting activity is stopped can in turn be verified using a *GBox*. Thus, the control loop of *Guerilla Sensing* is closed.

4 Guerilla Sensing Realization

An environmental information system matching the *Guerilla Sensing* approach has been developed by 11 students within a year.[5] The system consists of three major components: 1) one or more *GBoxes*, 2) a *GPlatform* and 3) one or many *GClients* as shown in Fig. 2. Environmental parameters are observed by a *GBox*. A *GBox* transmits data to the *GPlatform*. A user interact with the *GPlatform* using a *GClient* via a webpage-based interface[6].

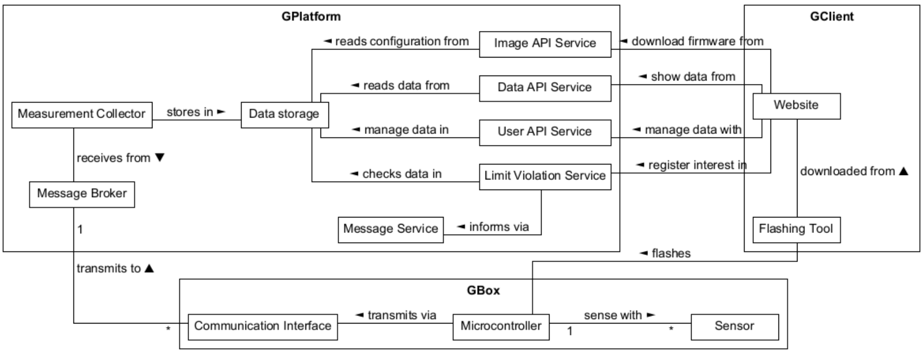

Fig. 2: *Guerilla Sensing* Architecture

A *GBox* (bottom part in Fig. 2) is composed of a microcontroller, mission-specific sensors, and a communication interface. Various microcontrollers compatible with the *Arduino* framework are supported such as the *ESP32*. Temperature, humidity, air pressure, soil

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[6] `https://www.guerilla-sensing.de/`

moisture, radioactivity, redox potential, pH-value, water conductivity, fine dust, and various gas sensors are supported. As communication interfaces, WiFi, LoRa, and GSM technologies are implemented. A user can build a *GBox* according to an environmental measuring scenario, he or she is interested in. The user gets various support by the platform website. On the platform website, a user can select the desired components using a graphical configurator that exists in a simple and in an expert mode version. Based on the specified configuration, the *GPlatform* automatically creates a specific firmware and offers it for download. Using a *Flashing Tool*, easily obtainable by download, a user then can forwardly install the generated firmware on a *GBox*. Finally, a manual, also published by the website, helps with assembly of the already selected components in order to obtain a ready-to-use customized *GBox*. In Fig. 3, an assembled *GBox* is shown. The *GBox* consists of a *ESP32* microcontroller with a LoRa communication interface. The sensors are chosen such that the GBox can measure fine dust, temperature, and humidity. Two batteries are connected to the GBox for autonomous operation. All components of the GBox are housed in a 3D-printed case.

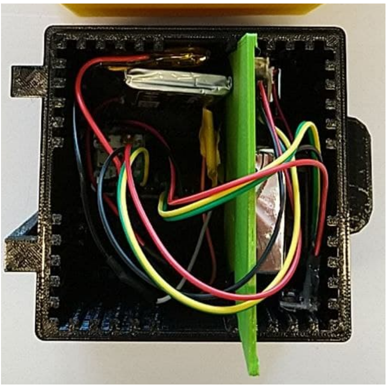

Fig. 3: A sample *GBox*.

A operating *GBox* transmits the measured data to the *Message Broker* of the *GPlatform* (top left part in Fig. 2). Communication with the *Message Broker* is done using the *MQTT* (Message Queuing Telemetry Transport) protocol. The messages received by the *Message Broker* include the unique identifier of the sending *GBox*. The *Measurement Collector* receives the messages and stores the received values together with identifier in a relational database (*Data storage*). Afterwards, the values can be accessed via the *Data API Service*.

With a *GClient* (top right part in Fig. 2), such as a personal computer or mobile phone, the user can access the website. The website uses the *Data API Service*, among others, to visualize the measured values on a map and to display trends over time. Also user-specific settings can be made on the website via the *User API Service*. Among other features, it is possible to delay the publication of measured values for a *GBox* and to conceal its true location for some amount of time. These features allow the covert observation of environmental parameters if doing so openly would hamper the measuring process. As a consequence, there is no chance to detect hidden measurements via the platform itself. Finally, people can register themself on the website for information or events, he or she is interested in, e.g., limit violations. The *Limit Violation Service* checks cyclically whether any exceedance has been measured. If there is a limit violation, then the *Limit Violation Service* notifies all people who have registered for the respective limit violation via the *Message Service* using an e-mail. The limits to which a user can subscribe, like the recommendation of the European Union for fine-dust concentration [EU08], are stored in the *Datastorage* .

5 Guerilla Sensing Application

The *Guerilla Sensing* approach has already been applied to some case studies, in order to exemplarily evaluate its functionality (i.e. prove its concept) in the context of a large city. The scenarios described here are supposed to show the suitability of important design goals of *Guerilla Sensing*, the functionality in practice of a *GBox*, the *GPlatform*, and the communication techniques connecting them. The used sensors are all off-the-shelf and low-cost. Unfortunately their measurements are not too scientifically accurate. But if the observed environmental parameter changes significantly, the sensors are capable of sensing this deviation. Furthermore, the *GBox* offers the necessary interfaces to connect high-quality sensors, in case an application actually demands it.

Scenario A: Measuring the radiation of a castor transport: Nuclear power plants produce radioactive waste. This waste is often transported over railways to a safe disposal facility. Some people, living or working close to the transportation route, do fear radiation overexposure. To protect people and environment from radiation overexposure, radioactive waste is incarcerated in massive highly radiation-protecting hulls (called castors). In this case study, we want to verify whether castors actually do their dedicated jobs. Furthermore, the exact date of a castor transportation is typically classified, thus, the setup was spontaneously done within a couple hours, evaluating the simple and fast adaptation of *Guerilla Sensing*.

In the scope of this scenario, *GBox* is equipped with a radiation sensor of *RadiationD-v1.1(caJOE)* type [Ac19]. The sensor measures β-radiation in range of 100 mR/h to 1800 mR/h and γ-radiation in range of 20 mR/h to 120 mR/h. It is placed in a cardboard box, together with an ESP32 microcontroller. As communication technique, WiFi-technology is used. In sum, the costs for the *GBox* for this specific scenario added up to 75€ [Bl21, p. 254]. This includes the microcontroller, communication module, sensors, housing, wiring, and battery. The box is placed on a leveled wall in 1.2 m height behind a 4 mm thick glass window. The railway track is straight line-of-sight in a distance of 46 m.

On November 3, 2020, at 20:35, the castor train has passed the *GBox* in the described distance. Figure 4 shows the radiation measurements of that day. Obviously and luckily, the *GBox* did not measure any significant changes in radiation in moment of the trains passage (arrow in Fig. 4). Thus, the castor seemed to work as supposed, shielding the radioactive waste as that no significant amount of radiation was released. We, thus, are confident that no harm neither for people nor the environment stemmed from the castor in the observed track section. *Guerilla Sensing* worked flawlessly despite the spontaneous character of the scenario.

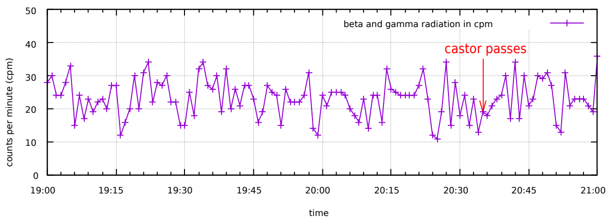

Fig. 4: Timeplot over β- and γ-radiation. At 20:35 a castor passes.

Scenario B: Measuring and logging fine dust particles near two public schools: Schools in large cities are often close to major roads. Parents worry about the health of their children and question their children's school to being a safe place. A schools' administration often does not know how to cope with those fears or is afraid of too many fine dust particles forcing the school to be temporarily closed.

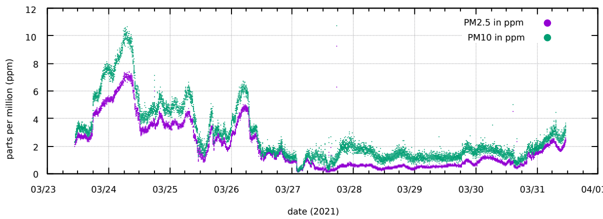

Fig. 5: PM2.5 and PM10 concentration near a school over eight days.

Two *GBoxes* equipped with an SDS011 [No15] fine dust sensor each, were installed in *guerilla*-like operations. This was necessary due to the fact that a school in a potentially highly fine dust polluted area refrained from any cooperation and explained their behavior by bizarre and administrative hindrances. The *GBoxes* operated exposed to the forces of nature, on battery supply and in the danger of being recognized. Different communication techniques had to be used due to different characteristics at the measuring location. The sensor measured fine dust PM10 (particles smaller than 10 µm) and PM2.5 (particles smaller than 2.5 µm) seperately in a range from 0 µg m^{-3} to 999.9 µg m^{-3}. The *GBoxes* were hidden outdoors in about 2 m height near the school premises. In sum, the costs for each *GBox* for this specific scenario added up to 85€ [Bl21, p. 254]. This includes the microcontroller, communication module, sensors, housing, wiring, and battery.

In case of the first measurement series, shown in Figure 5, a GBox was connected to the *GPlatform* via *GSM*. The fine dust concentration was measured every minute over a duration of eight days. This way, the *GBox* worked about 24 h before the battery was drained and had to be replaced. Thereby, the PM2.5 fine-dust concentration was at its maximum in the morning of Wednesday, the 24th of March, of 7 µg m^{-3}, which was not even close to the limit value of 25 µg m^{-3}. The PM10 fine dust concentration was 10.5 µg m^{-3} at that time. The European Union recommends an annual average concentration in atmosphere below 25 µg m^{-3} for PM2.5 and 40 µg m^{-3} for PM10 [EU08].

In case of the second measurement series, a GBox was connected to the *GPlatform* via *LoRaWAN* through a *LoRaWAN* gateway [Ha18]. The fine dust concentration was measured every 50 s for a duration of two days. This way, the *GBox* worked for about 36 h before the battery was drained and had to be replaced. Again, the measurements never came even close to the recommended limit values.

In conclusion, the *GBoxes* measured fine dust concentration far below the limit values, recommended by the European Union. At the time of measurement, the observed schools were uncritical in regard of fine dust. The *GBoxes* stayed intact and undiscovered over the long measuring interval and were capable of measuring fine dust even in low concentrations. Both communication techniques worked successfully, proving the flexibility of *Guerilla Sensing* in this regard. As lower values were observed potentially due to reduced traffic in pandemic times, measurements should be repeated, when society is „back-to-normal.“Nevertheless, the scenario shows how the *Guerilla Sensing* approach can be used such that all parties involved benefit: the parents by now having their peace of mind and school administration by being assumed that they truly offer a secure learning location for their students.

6 Conclusion

The *Guerilla Sensing* approach allows to measure, log, analyze, and report a variety of environmental parameters. By using differing application scenarios, we could successfully prove the idea and realization of *Guerilla Sensing*. It is very flexible according to communication techniques, as it supports WiFi, GSM, and LoRa technology. The *GBox* is small enough to be effectively hidden and can work autonomously without any wired energy or wired communication supply. By that, unrecognized *guerilla*-like operations are possible, as we have demonstrated by Scenario B. Together with a solid housing, this enables the *GBox* to run for indoor as well as outdoor or segregated measurement scenarios.

Due to the fact that the *GPlatform* automatically generates the individual firmware of a *GBox*, no programming skills are required to run a sensor. The components of a *GBox* are off-the-shelf hardware that can be ordered at common online stores for a small amount of money (typically between 40€ and 130€, depending on the set of required sensors). The *GPlatform* assists in the assembly of the *GBox* by detailed step-by-step-guides. A simple assembly process consists of connecting wires, which truly requires only basic knowledge.

The *GPlatform* sends a e-mail to interested entities, if a legal limit is exceeded. It shows all measured data to all the platform users, if a *GBox* operator wishes to do so. *GPlatform* users can inform themselves and interested entities about the environmental situation in their region when *GBoxes* are present.

In conclusion, the *Guerilla Sensing* approach enables citizen to resist against environmental exploitation by providing automated functions to observe, discover, log, visualize, and report to politics & authorities in charge, demanding or urging them to act. In this respect, we regard *Guerilla Sensing* as a valuable asset in difficult times.

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