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A CITIZEN SCIENCE APPROACH TO COLLECT COMBINED NOISE EXPOSURE AND SURVEY DATA

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ABSTRACT

Collecting region-wide noise exposure in combination with survey data is a demanding task, typically entailing large hardware and operational costs. A protocol is developed to relax the costs by relying on a citizen science approach. By implementing a high-quality digital mems microphone on a low-cost hardware platform, an affordable edge device was made operational, allowing high flexibility in sound signal processing and choice of noise indicators to be reported. A user dashboard connects external functionality to gather survey data, measurement location meta-data and short-term annoyance annotations. Finally, all the data is merged for potential use in policy support. Efficient use of the noise monitors is ensured by a hierarchical distribution in a hub-like approach. In this, a citizen acts as a hub administrator and becomes responsible for a limited number of measurement setups. This hub administrator communicates within his local citizen network to distribute and move the equipment across different noise environments. In this publication, the findings from the citizen-based environmental noise monitoring protocol tests are presented.

Keywords: noise monitoring, citizen science, policy support

1. INTRODUCTION

In 2019-2020, an extensive evaluation of the noise indicators in this environmental report was performed and a trajectory was presented to improve the quality and sustainability of these long-term noise indicators [1]. One of the elements in this indicator scheme is to collect survey and noise monitoring data simultaneously.
Collecting scientific data through citizen science is a highly active field [2-5]. The European union adopted and support the inclusion of citizen science at different levels [5-6]. The overall aim of this paper is to investigate the potential to include citizen science into noise monitoring and survey data collection. At Internoise 2024, the initial setup was presented [7]. This publication will present the modifications to this original plan and add the results of the citizen science approach.
It can enable monitoring programs at a highly reduced cost. Other applications within scope are the monitoring of initiatives triggered by local authorities. Local initiative would include the monitoring of recreational activities, mobility plans etc. Similarly, road traffic agencies can monitor infrastructure projects using citizen support. Projects with a focus on health are also within scope.

2. TECHNOLOGY COMPONENTS

The low-cost noise monitor, based on a Asus Tinkerboard R2.0 is described in-dept in previous work [7], only the modifications to the hardware will be added. The main change is the implementation of a newer version of the digital MEMS microphone (Infineon-IM69D120). The MEMS has a higher dynamic range, resulting in a noise floor of 24 dBA, 4 dB lower than the previous version.
The noise monitors are processing the data on the device using local databases and local agents. The highest resolution is third octave bands in a 1/8 second temporal resolution. The measurements are next aggregated to an extended set of indicators in a 10 second resolution and uploaded to a user dashboard.
In addition, the full-resolution data is uploaded to a parallel cloud service for detailed reporting by the application owners and to enable additional indicator calculations. In Figure 1, three hours of 10 second $L_{Aeq,10s}$ and five aggregated spectral bands are visualized for the user. The

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high frequencies (green line) illustrate the bird activity at this location. The low frequencies (grey and blue lines) focus on low frequency traffic events through engine noise.

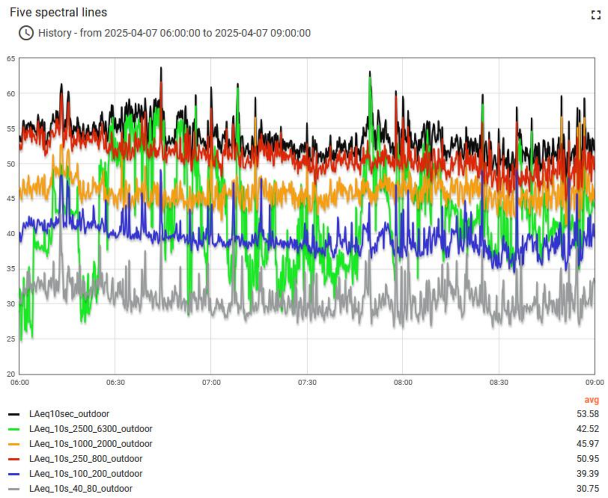

Figure 1: The last 15 minutes in a $L_{Aeq,10sec}$ (black) with a basic illustration of the spectral content, grouped into five components (colors).

In Figure 2, seven days of $L_{Aeq,15min}$ and a selection of statistical levels are shown. These types of visualizations are examples of user feedback that can motivate people to join these citizen science projects.

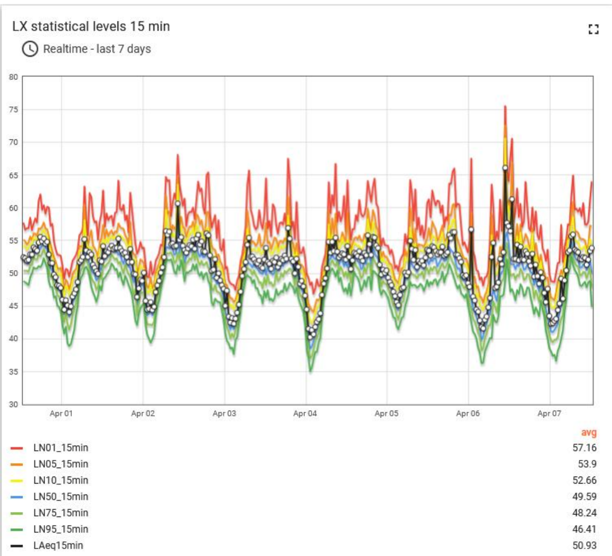

Figure 2: Seven days of LAeq,15min (black line) and matching statistical levels (colors).

2.1 HUB approach and citizen intake procedure

The central issue is how to reach the volunteers required for a specific application and how to achieve this at a cost-efficient manner. The main benefit of a citizen science approach is the reduced support cost by including the public to manage and set up the noise monitors. No local support at the dwellings of the volunteers is required, managing a campaign is reduced to technical support and a managing team to distribute the equipment to local hub administrators who manage a limited amount of noise monitors in their local network. This results in a hierarchical approach, reducing the communication of the managing team to the local hub administrators, who each manage their local citizen scientists (see Figure 3).
The alternative is a centralized approach where the managing team performs all communication with each individual volunteer. The centralized approach will rely on more hardware and less on the distributional aspects of long-term data collections compared to the hub-like approach.

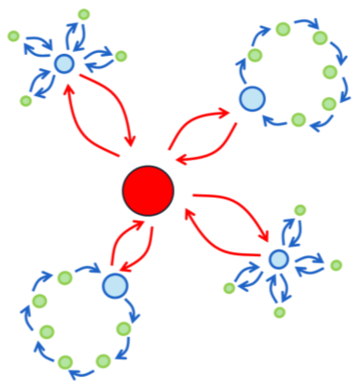

Figure 3: Hub-like implementation. The managing team (red) addresses the hub administrators (blue), who manage the volunteering citizens (green).

2.2 Selecting hub administrators

The primary goal - achieving a representative population - is partially contradictory to the inclusion of volunteering citizens. To investigate this, several types of hub administrators are evaluated in a number of pilot measurement campaigns. The hub administrators are contacted by the administrative team, receive an introduction and a limited set of noise monitors (maximum four units). Once the hub administrators are activated, the citizen selection process can start.

2.3 The citizen intake and data collection process

The citizen is contacted by his hub administrator. After a successful registration and the completion of a general noise survey, the volunteer receives an e-mail with the documentation to a dashboard matching their noise monitoring time window. The hub administrator provides the noise monitor.

At deployment of the equipment, the citizen fills in a metadata survey on the specifics of the monitoring position and he can provide noise annoyance annotations through buttons on a dashboard.

At the end of the monitoring period, the monitor is returned to the hub administrator or directly to the next user, depending on the hub type. The noise monitoring results are presented in a personal report. The data is provided in a digital format. This report and data delivery is the only reward for the effort of the citizens.

2.4 The project management tool

To manage communication over the entire chain, a managing tool is necessary. This tool provides administrative functions for the application managers and hub administrators. It is also the place to evaluate the potential biases in the citizen selection process.

2.5 The reported noise indicators

Since citizen science relies completely on the voluntary support of the public to achieve both the policy and scientific goals, a non-monetary return is in place. The users get access to monitoring data in high resolution.

Figure 4 to Figure 8 provide a set of visualizations provided to the citizens. The citizens receive this as a zipped directory as a token for their effort.

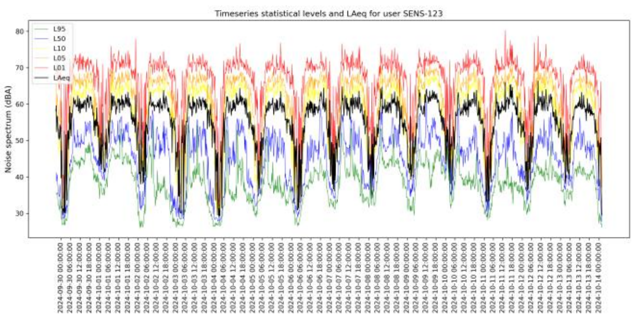

Figure 4: Overview of the statistical levels (colors) and $L_{Aeq,15min}$ for the entire measurement period.

The time series of the statistical levels give an overview of the noise environment and its dynamics (Figure 4). In Figure 5, the Harmonica-Index is visualized. The harmonica-Index splits the noise exposure in a background and a event-like contribution and translates the result into a human interpretable evaluation, sensitive to the period of the day [8].

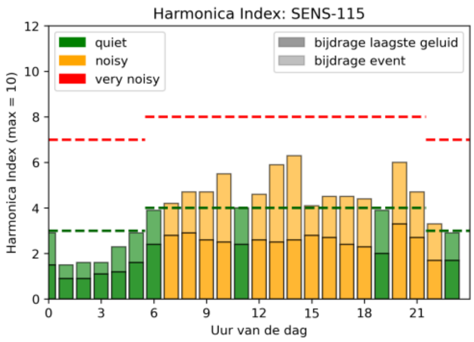

Figure 5: Visualization of the Harmonica Index (in Dutch).

The high-resolution time series are available in clips of 15 minutes, including spectral details (Figure 6).

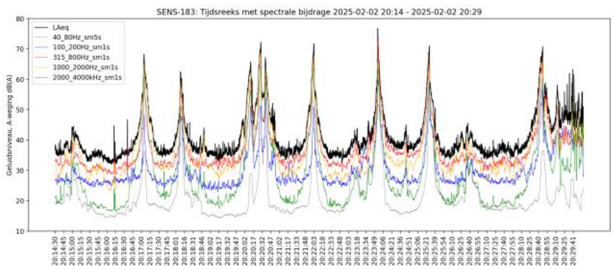

Figure 6: 15-minute time series including a smoothed contribution of the spectra content (under revision).

Figure 7 plots the distribution of statistical levels. It gives an instant view of the changes in the noise climate at the dwelling. Do the noise levels drop at night? Are the peak levels systematic are sporadic? Is the noise climate dynamic or not?

These visualizations require some guidance and information for interpretation by a nonexpert. A general document explains the visualizations and their potential use. This is both an education aspect as a communication tool to attract and activate new and hub administrators and volunteers.

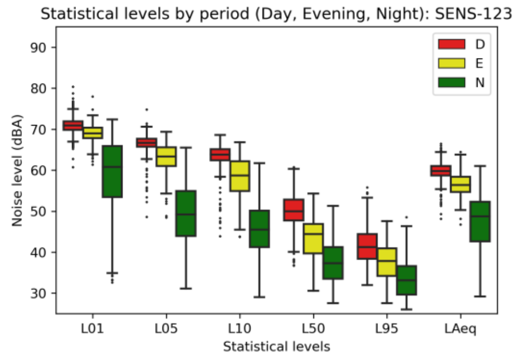

Figure 7: Distribution of the statistical levels by period of the day.

The citizen is also interested in actual exposure values to compare with other people. In Figure 8, the tables with the day-to-day variation in $L_{Aeq,day}$, $L_{Aeq,evening}$, $L_{Aeq,night}$ and L_{den} and the average statistical levels by hour of the day are provided.

Date	D	E	N	LDEN
2024-09-30	60,2	56,8	51,4	60,9
2024-10-01	60,6	57,6	51,0	61,1
2024-10-02	60,3	56,3	51,9	61,1
2024-10-03	60,1	57,0	50,3	60,5
2024-10-04	60,4	57,9	50,3	60,9
2024-10-05	59,4	56,6	49,9	60,0
2024-10-06	59,0	59,3	50,9	61,0
2024-10-07	60,4	56,9	50,2	60,6
2024-10-08	60,2	56,6	50,9	60,7
2024-10-09	61,5	58,1	51,2	61,7
2024-10-10	60,0	58,6	51,8	61,4
2024-10-11	60,8	58,2	50,3	61,1
2024-10-12	60,6	56,1	50,6	60,7
2024-10-13	59,1	56,2	49,4	59,6

	L01	L05	L10	L50	L95	LAEQ
00:00	62,7	51,9	46,6	37,4	32,8	49,6
01:00	57,5	46,2	42,2	35,6	32,0	45,3
02:00	59,6	45,0	41,4	35,6	31,6	47,6
03:00	57,5	45,5	41,9	34,7	30,9	45,2
04:00	60,5	47,8	43,6	36,5	32,2	47,8
05:00	63,4	52,7	47,6	39,7	35,7	50,5
06:00	66,3	58,0	52,6	42,9	39,0	52,9
07:00	70,5	64,8	61,3	49,8	44,6	58,6
08:00	70,7	66,6	63,7	52,0	45,2	59,9
09:00	70,9	66,0	62,7	48,8	42,8	59,3
10:00	71,0	66,2	63,0	48,5	40,4	59,4
11:00	71,2	66,5	63,5	48,8	40,3	59,7
12:00	71,3	66,6	63,7	50,6	41,3	60,0
13:00	71,4	66,7	63,6	51,2	42,6	60,1
14:00	71,7	67,2	64,3	50,6	42,3	60,4
15:00	71,2	67,1	64,4	50,9	41,7	60,3
16:00	71,7	67,5	64,9	51,2	41,1	60,8
17:00	71,5	67,5	65,0	52,5	41,6	60,9
18:00	71,4	67,4	65,0	52,0	40,5	60,8
19:00	70,4	66,3	63,4	48,6	40,1	59,3
20:00	69,4	64,4	60,3	44,3	37,8	57,4
21:00	68,8	62,7	57,9	42,1	37,0	56,1
22:00	68,3	60,1	54,4	40,2	35,7	54,6
23:00	66,4	57,8	52,0	39,0	34,2	52,8

Figure 8: Tables with day-to-day variation in L_{Aeq} and L_{den} (left) and the average statistical levels by hour of the day.

3. CITIZEN SCIENCE CAMPAIGNS

3.1 Reach the public, exploring the options.

In prior work, schoolteachers collaborated in a citizen science approach to merge STEM education with noise awareness and noise monitoring [9]. To continue on this track, four secondary schools responded to a small outreach. In addition to the normal education trajectory, a link was made to a highly focused school initiative, where the strongest pupils in the primary school were provided with more challenging content. Fifteen gifted pupils of 10 to 11 years old joined the project and had the opportunity to have face-to-face contact with a noise expert. In total, there were 5 school and 36 pupils involved.

A second group that was explored are existing citizen organizations, with or without a focus on (local) environmental issues. Especially the environmental action groups are eager to participate and perform repeated measurements over time as illustrated in prior work [10].

4. DISCUSSION

4.1 Hardware improvements

The user experience was negatively affected by the low quality of the 4G communication. The position of the unit impacts the communication quality, but it is expected that a better 4G modem, 4G provider and 4G antenna can solve this issue in the future.

The equipment was outbound for more than six months without technical support. No intermediate quality checks were performed between the different pilots due to operational limitations. The weather conditions were harsh, the monitors endured a heat wave during the preparatory measurements and were exposed to rain, snow and freezing periods during the pilots. One MEMS microphone on ten units failed. Including operational quality checks of the monitors to detect issues early-on is advised.

Overall, the equipment provide the required robustness and data quality.

4.2 Low-cost applications

The required effort to achieve a high quality and user friendliness application was underestimated. Citizens are in daily practice used to high quality applications on both web and smartphone. Advanced application development to attract citizens and to keep the initiative successful on the long-term will be necessary. Additional functionality to facilitate the different administrative roles is necessary. We advise integrating the communication between the administrative roles, hub administrators and citizens into a single application with different levels of access to monitoring data and citizen and hub administrator activity.

4.3 Application types and deployment strategies

4.3.1 Application types

We evaluated two types of applications and addressed the deployment strategy separately. The first group are the general-purpose application for noise annoyance, noise exposure and health related applications. The second group are projects with a local research question with the focus on exposure only.

4.3.2 Population-based applications

In the first group, a proper evaluation of the potential spatial and socio-economic biases is detrimental to the outcome. The advice is here to rely on a combination of addressing school and non-environment related citizen collections. The population at the schools has a good social mix but reaches only families with children. Other citizen collections with a focus on other age groups, both young and old, are necessary to adjust for their underrepresentation in families with children. Selection though social media and active senior organizations can fill in the missing population segment.

4.3.3 Schools and educational projects

Schools and teachers are interesting hub type but to engage them more strongly, a long-term perspective is necessary. They have two requests to increase their own return on investment: (1) extend and integrate the documentation and functionality to match the official learning objectives and (2) provide a long-term availability of this functionality. These requests align at full with the aim of the project, collecting repeated data for policy support.

5. CONCLUSION

This project provides a basic protocol to include citizen science into the data collection for noise and annoyance evaluations. The technical component provides a low-cost noise monitoring equipment with high quality data.
The approach of working in hierarchical hub deployment is evaluated as valid. The most successful approaches are schools and citizen collectives.

6. ACKNOWLEDGMENTS

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