EVALUATION OF LEISURE NOISE IN URBAN ENVIRONMENTS

An approach based on low-cost sound monitoring systems and artificial intelligence

Paola Weitbrecht [1], Carolina Monteiro [2], Cecilia Jardim [3],
Marcel Borin [4], Marcos Holtz [5], Leonardo Jacomussi [6]
[1] Harmonia, paola@harmonia.global
[2] Harmonia, carolina.monteiro@harmonia.global
[3] Harmonia, cecilia.jardim@harmonia.global
[4] Harmonia, marcel.borin@harmonia.global
[5] Harmonia, marcos.holtz@harmonia.global
[6] Harmonia, leonardo.jacomussi@harmonia.global

ABSTRACT: With the growing concern about noise pollution and its effects on health and well-being, the development of effective urban sound planning is becoming highly necessary. However, the soundscape of the urban settlements is a complex composition of different sound sources and should be faced with a multidisciplinary approach. The urban sound planning concept addresses not only the reduction and time of exposure to noise, but also the subjective and qualitative nature of sound, which enables the design of favorable acoustic environments. In this context, one sound source that stands out is the leisure noise. Being composed by diverse sources, it is hard to be characterized, and standardized prediction or measuring methods are still under development. However, it represents essentially the liveliness of the city and the important actions of relaxation and socialization of their citizens. Different international research study how sound monitoring stations integrated with the latest technologies could improve the collection of quantitative data regarding recreational noise, other studies have developed questionnaires to understand its subjective aspects. Furthermore, in São Paulo, a low-cost sound sensor was created with the aim of facilitating urban noise monitoring. An overview of its development process will be presented in this article, as well as the evolution of machine learning for urban sound source recognition.

KEYWORDS: Sound monitoring, soundscape, source characterization.

***TÍTULO:* AVALIAÇÃO DO RUÍDO DE LAZER EM MEIO URBANO: UMA ABORDAGEM BASEADA EM SISTEMAS DE MONITORAMENTO SONORO DE BAIXO CUSTO E INTELIGÊNCIA ARTIFICIAL**

RESUMO: *Com a crescente preocupação com a poluição sonora e os seus efeitos na saúde e no bem-estar, o desenvolvimento de um planejamento sonoro urbano eficaz torna-se extremamente necessário. No entanto, a paisagem sonora dos aglomerados urbanos é uma composição complexa de diferentes fontes e deve ser confrontada com uma abordagem multidisciplinar. O conceito de planejamento sonoro urbano aborda não somente a redução e o tempo de exposição ao ruído, mas também a natureza subjetiva e qualitativa do som, o que permite a concepção de ambientes acústicos favoráveis. Neste contexto, uma fonte sonora que se destaca é o ruído de lazer. Composta por diversas fontes, é de difícil caracterização e métodos de previsão ou medição padronizados ainda estão em desenvolvimento. No entanto, ela representa essencialmente a vivacidade da cidade e as importantes ações de relaxamento e socialização dos seus cidadãos. Diferentes grupos de pesquisa internacionais estudam como estações de monitoramento sonoro integradas com as mais recentes tecnologias poderiam melhorar a coleta de dados quantitativos relativos ao ruído recreativo, outros estudos desenvolveram questionários para compreender os seus aspectos subjetivos. Além disso, em São Paulo, foi criado um sensor sonoro de baixo custo com o objetivo de facilitar o monitoramento do ruído urbano. Uma visão geral do seu processo de desenvolvimento será apresentada neste*

DOI: 10.55753/aev.v38e55.237

artigo, bem como a evolução da aprendizagem de máquinas – machine learning - para o reconhecimento de fontes sonoras urbanas.

PALAVRAS-CHAVE: *Monitoramento sonoro, paisagem sonora, caracterização da fonte.*

1. INTRODUCTION

As the population of cities and megacities increases [1], urban areas are becoming the common landscapes, and so is the soundscape they generate. According to the World Health Organization (WHO) [2], noise pollution is already one of the greatest environmental risks to health and well-being and is a growing concern for civilians and policy makers. In this context, an effective urban sound planning becomes increasingly necessary, in which, along with measures of noise mitigation, the attractive and positive sound environment is promoted.

A common approach when considering urban noise management is the development of noise maps. Although being an important diagnosis tool, that enables estimating the extent of the population exposed to high levels of noise, they do not present a holistic view of urban soundscape and most of the time they are dependent on four different noise sources such as road traffic, rail traffic, air traffic, and industry [3]. A much broader approach is proposed in urban soundscape planning [4], where along with the collection of quantitative data, the subjective aspect of the quality of the sound is considered. In addition, citizens participation and the collaborative work of the different stakeholders is encouraged. As a result, this approach enables the design of favorable acoustic environments that suit the city context and user experience.

In this context, a specific sound source stands out among others, and it has the potential to characterize the liveliness of a city and represent the necessity of relaxation and socialization of citizens. Leisure noise or recreation noise, besides playing an important role in the urban ambience, lies between the contradiction of those who participate in the activity and those who live nearby. While the first group experiences this as a pleasure, the second group understands it as a burden for their rest [5].

In São Paulo, from 2019 to 2022, noise complaints increased by 67%, where the main sound sources are leisure activities and construction sites [6, 7]. Despite having this considerable effect on people and cities lives, leisure noise is not yet effectively addressed by local authorities. The difficulty with this type of noise lies in the lack of measurements and prediction standards, the composition of various acoustic properties of the noise sources (e.g., music, conversations, etc.), and the strong subjective nature inherent in festive activities.

2. STATE OF ART

The city of São Paulo is home to a variety of cultural and leisure activities such as museums, theaters, public parks, festivals, shopping streets, among other open-air activities. It also hosts one of the most vibrant nightlives of Latin America with clubs, late night bars and restaurants [8]. Despite their importance to the local economy, for inhabitants' relaxation and for the vitality of the city, recreational activities can cause noise and nuisance to the neighborhood. The city's masterplan contains guidelines on noise levels for urban planning according to land use. In residential areas, the noise level should be kept below or up to 50 dB during the day (7:00 to 18:00), 45 dB at evening (19:00 p.m. to 21:00 p.m.) and 40 dB at night (22:00 to 06:00) [9].

On a national level, the Brazilian standard ABNT NBR 10151, "Acoustics — Measurement and evaluation of sound pressure levels in inhabited environments — Application for general use" [10], contains technical procedures for sound pressure level measurements and noise limits according to the purpose of use, occupation of the land and period of day or night. Despite being effective for measuring and evaluating sound levels originated by local establishments, it lacks a procedure for addressing leisure noise resulting from people gathering in streets and parks, for example.

The main challenge remains the lack of methods for assessing and measuring leisure noise. A first step to be considered when creating any noise management strategy is the collection of qualitative and quantitative data [3]. A variety of studies can be found on how this data can be assembled. In Spain [11], for example, a proposed method to predict noise levels in a recreational street is based on long-term measurements, crowd density, noise exposure, building height and number of recreational facilities. Whereas, in Milan and Turin [12], questionnaires were implemented alongside sound pressure level measurements to understand noise annoyance in the so called “movida districts”.

The use of Industry 4.0 technologies has become more accessible and effective for quantitative data collection. In the district of San Salvario (in Turin) and in Paris, the adoption of an IoT noise monitoring network provided sufficient data on noise levels in busy neighborhoods [13, 14]. Meanwhile, the “movida” district of San Salvario was used as a pilot study for the MONICA project [15]. In Paris, the MEDUSA sensor was developed with four different microphones and an integrated camera, 42 sensors were installed in 10 different neighborhood and reported noise annoyance from night-time activities. The aim of the project is to demonstrate the large-scale application of IoT in monitoring noise pollution, among other factors, in cultural performances in open-air settings. In addition, the San Salvario study used IoT technologies combined with behavioral rewards to reduce noise and minimize neighborhood annoyance.

In São Paulo, the creation of a low-cost monitoring station based on IoT and artificial intelligence was developed with the aim of monitoring the soundscape in the city. This system could be used as a first approach in characterizing leisure noise once it is an effective way of collecting quantitative data in long term. Allied to this technology, a digital platform gives access to the public to follow a vivid representation of the noise levels in which they find themselves, and the possibility to embed online surveys.

3. LOW-COST SOUND MONITORING SENSOR

The low-cost sound monitoring sensor was developed in three different fronts: software, hardware, and digital design. The sensor is based on hardware and peripherals of easy manipulation and prototyping. A single board computer (or SBC) that contains the same basic components as a conventional computer is the centerpiece of the set, followed by MEMS I2S microphone. As for the software, it was implemented in open-source languages such as Linux and Python. A 3G module guarantees access to the internet and connection to the cloud, where data management and communication rules between sensor, platform, and finally users are done.

Since the first conception, the sensor went through rigorous internal laboratory tests to assess the reliability of the obtained data. It was compared against a Class 1 commercial equipment, in different aspects (mainly overall sound levels and frequency bands), with different everyday sound sources and presented excellent performance [16]. Besides the internal tests, three sensors were tested in real life application, monitoring over 24 hours two construction sites in São Paulo. A Class 1 sound level meter was placed close to the sensors, so a comparison between the systems could be possible. Again, satisfactory performance was achieved in data reliability and in the ability to describe temporally and spatially the sound environment. Furthermore, the system was used to monitor large open-air events and met the expectations.

The third front, based on digital design, was the development of a web platform. The main goal of this page was to create sufficient usability and accessibility so that users with different levels of acoustic knowledge could access the data and get relevant information during and after the monitoring period. Additionally, an artificial intelligence system for the automatic identification of sound sources was trained, and the classification results can be found on the platform.

3.1. Artificial Intelligence

A sound monitoring station can generate a huge amount of data, especially for long-term monitoring. In cities, complex environments are common, and many types of noise sources often occur simultaneously. In the cases where it is desired to know the source of noise, an automatic sound identification would be useful for reducing time and costs, as well as serving as an excellent tool for better understanding the soundscape.

Therefore, an algorithm using machine learning was developed to be embedded in the noise monitoring sensor to identify the sound sources. Before the implementation, an audio dataset was created collecting recorded data from all over the city of São Paulo using the described methodology in [17]. As being the most important part of a supervised machine learning model, the dataset was carefully labelled using the following 13 classes:

1. Motorcycle
2. Car
3. Heavy vehicle (pass-by)
4. Heavy vehicle (idling)
5. Background noise
6. Human voice
7. Bird
8. Insect
9. Dog
10. Siren
11. Construction noise (impact)
12. Construction noise (non-impact)
13. Music

The dataset was built to contain the main sound sources in the city, including a variety of classes such as vehicles, construction noise, biological sounds, and human activity sounds. The “dog” and “siren” sound classes were the only ones acquired from an existing free available dataset, the UrbanSound8K [18], which is a benchmark in the area.

During the sound monitoring, the stations send equivalent sound pressure level data every 5 minutes ($L_{Aeq,5min}$) to an online cloud. The classifications are performed every time the equivalent sound pressure level surpasses the trigger limit in the period of 5 minutes. Once the trigger is activated, the 5 minutes audio recordings are segmented in 4 seconds samples, which are used as input to the model, since a fixed data size is necessary. Thus, one classification label is acquired every 4 seconds in a total of 75 labels in the 5 minutes period.

To increase the data understanding and simplify long-term monitoring, a corresponding primary sound source was assigned to each five-minute segment. The choice of the main source was made using the Sound Exposure Level (SEL) quantity, since it considers both sound pressure level (SPL) and time exposure. The equation below shows how it is done:

$$SEL = SPL + 10 \log (t) \quad (1)$$

The variable t represents how much time a certain sound source is identified during the 5 minutes length. For example, considering a sound class with an average SPL (L_{Aeq}) of 70 dB which appears in 10 segments of 4 seconds, it would result in 86 dB of SEL. In summary, the 5 minutes audio segment is assigned to the sound class that presents the higher SEL.

The machine learning model architecture chosen to the task is a Convolutional Neural Network (CNN) mainly due to its wide application in the field of sound classification and usual better performance compared to other standard models [19]. As an input to the model, the 4 seconds audio samples are pre-processed into Mel Log spectrogram, using 64 Mel bands for frequency resolution. It is relevant to point out that the frequency sampling of 22050 Hz is used, considering that the main information of a spectrum is generally below 10 kHz.

An average accuracy of 88.1% was found for the model [17]. It is important to notice the difficulty for the model when discriminating among the means of transportation, since they present similar source of sound generation, which is mainly by combustion engine at low frequency. Thus, a decrease in the accuracy is noticeable to the region of 70% regarding traffic noise.

4. CONCLUSION

The soundscape in urban settlements is a complex composition of different sound sources. While some of them can be considered annoying and even harmful for human health and wellbeing, others can dictate the liveliness of the city and represent favorable acoustic environments. Therefore, when creating urban noise management policies, a holistic approach, that considers not only the mitigation or abatement of noise, but also the subjective and positive aspects of sound, should be adopted.

São Paulo is the largest city in Brazil, and like other megacities, it can be a noisy environment. However, one noise source stands out from the others, mainly due to its subjective nature and difficulty in being addressed, that is leisure noise. Since there are none standardized prediction or measurement methods, different studies in Europe have been proposing the use of monitoring stations to collect quantitative data. Embedded with IoT technologies and combined with qualitative data collection, these systems are important tools to understand the behavior of recreational noise in outdoor environments.

With the aim of monitoring noise pollution in cities, and being a first approach to characterizing leisure noise, a low-cost monitoring sensor was developed based on three fronts: software, hardware, and digital design. An online platform is available for the public to follow noise pressure levels enabling the interaction of citizens. The use of artificial intelligence facilitates the understanding of the city's complex soundscape, with the main sound source labeled every 5 minutes using the Sound Exposure Level, since it considers both level and time exposure.

As a conclusion, the use of smart technologies in urban sound planning can be considered favorable for the collection of quantitative data. Especially when addressing leisure noise, low-cost sound monitoring systems can be great allies. However, this is only one part of the approach since the subjective and qualitative aspects of recreational activities must be considered.

REFERENCES

(1) United Nations. (2018). *68% of the world population projected to live in urban areas by 2050, says UN*. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html (accessed April 19, 2022).

(2) Roberts, J. (2018). *Noise pollution is one of the biggest health risks in city life | Research and Innovation*. https://ec.europa.eu/research-and-innovation/en/horizon-magazine/noise-pollution-one-biggest-health-risks-city-life (accessed November 23, 2022).

(3) Kloth, M.; Vancluysen, K.; Clement, F.; Lars Ellebjerg, P. (2008). *Practitioner Handbook for Local Noise Action Plans: Recommendations from the SILENCE project*, 124.

(4) Kropp, W. *et al*. (2016). *Urban sound planning - The SONORUS project*.

(5) Bernfeld, D.; Revol, C.; Mietlicki, F. (2022). Regulation of nightlife noise in Paris: the contribution of innovative monitoring and perspectives. *Proceedings of the 51st International Congress and Exposition on Noise Control Engineering* (Inter-noise 2022).

(6) UOL. (2022). Reclamações por barulho crescem e superam nível pré-pandemia em SP. *UOL Notícias*. https://noticias.uol.com.br/ultimas-noticias/agencia-estado/2022/07/05/reclamacoes-por-barulho-crescem-e-superam-nivel-pre-pandemia-em-sp.htm (accessed November 23, 2022).

(7) G1. (2022). *No de reclamações de barulho na cidade de SP em 2022 é maior que antes de pandemia*. https://g1.globo.com/sp/sao-paulo/noticia/2022/07/19/no-de-reclamacoes-de-barulho-na-cidade-de-sp-em-2022-e-maior-que-antes-de-pandemia.ghtml (accessed November 23, 2022).

(8) Cidade de São Paulo. (2022). *Baixo Augusta*. https://cidadedesaopaulo.com/novidades/baixo-augusta/?lang=pt (accessed November 23, 2022).

(9) São Paulo (Município). (2014). Lei nº 16.050, de 31 de julho de 2014. Aprova a Política de Desenvolvimento Urbano e o Plano Diretor Estratégico do Município de São Paulo. *Diário Oficial do Município de São Paulo*.

(10) Associação Brasileira de Normas Técnicas (2019). *Acústica – Medição e avaliação de níveis de pressão sonora em áreas habitadas – Aplicação de uso geral* (ABNT NBR 10151).

(11) Ballesteros, M. J.; Fernández, M. D.; Flindell, I.; Torija, A. J.; Ballesteros, J. A. (2014). Estimating leisure noise in Spanish cities. *Applied Acoustics*, 86, 17–24. DOI: 10.1016/j.apacoust.2014.04.019.

(12) Ottoz, E.; Rizzi, L.; Nastasi, F. (2015). Recreational noise in Turin and Milan: impact and costs of movida for disturbed residents, *Proceedings of the 22nd International Congress on Sound and Vibration* (ICSV22).

(13) Revol, C.; Bernfeld, D.; Mietlicki, F. Regulation of nightlife noise in Paris: the contribution of innovative monitoring and perspectives. *Proceedings of the 51st International Congress and Exposition on Noise Control Engineering* (Inter-noise 2022).

(14) Gallo, E.; Ciarlo, E.; Santa, M.; Sposato, E.; Vincent, B.; Halbwachs, Y. (2018). Analysis of leisure noise levels and assessment of policies impact in San Salvario district, Torino (Italy), by low- cost IoT noise monitoring network. *Proceedings of the 11th European Congress and Exposition on Noise Control Engineering* (Euronoise 2018), 699–704.

(15) MONICA. (2019). *About MONICA - Sound and security applications for large, open-air events in the city*. https://www.monica-project.eu/home/about-monica/ (accessed September 11, 2022).

(16) Weitbrecht, P.; Jacomussi, L.; Borin, M.; Monteiro, C.; Jardim, C. MEMs Based Low-Cost Urban Noise Monitoring: Tests and Case Study. *Proceedings of the 51st International Congress and Exposition on Noise Control Engineering* (Inter-noise 2022).

(17) Borin, M.; Holtz, M.; Jacomussi, L.; Monteiro, C.; Weitbrecht, P.; Jardim C. (2022). Automatic identification of city intrusive noises using deep learning. *Anais do 12º Congresso Iberoamericano de Acústica e 29º Encontro da Sobrac* (FIA 2020/22).

(18) Salamon, J.; Jacoby, C.; Bello, J. P. (2014). A Dataset and Taxonomy for Urban Sound Research. *Proceedings of the 22nd ACM international conference on Multimedia* (MM '14), 1041–1044. DOI: 10.1145/2647868.2655045.

(19) Mu, W.; Yin, B.; Huang, X.; Xu, J.; Du, Z. (2021). Environmental sound classification using temporal-frequency attention based convolutional neural network. *Scientific Reports*, 11, 1–14. DOI: 10.1038/s41598-021-01045-4.